ASPHALT CONSTRUCTION

FOR

PAVEMENTS AND HIGHWAYS

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A POCKETBOOK FOR ENGINEERS
CONTRACTORS AND INSPECTORS

BY

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PREFACE

The increase in recent years in the amount of sheet asphalt pavement which is being laid in our cities and the extent of the asphaltic concrete and asphaltic broken stone surfaces which are being constructed on our country highways to resist the destructive action of motor vehicles, has created a demand for highway engineers, contractors, and inspectors, who are skilled in this work, far in excess of the supply. The result has been that many have entered these fields who do not realize the importance of careful attention to details which is necessary to insure complete success in this line of work. With a view to supplying the necessary information in regard to these details to the persons who have been mentioned, this pocket-book has been prepared with the hope that it will do something toward insuring better work in the future than has been done in some cases during recent years by inexperienced contractors and engineers, and supervised by inexperienced inspectors. Its form has been selected in order that it may be readily carried in the coat pocket, for reference on all occasions, something that cannot well be done with a larger book with stiff covers.

THE AUTHOR.

April, 1913.

CONTENTS

ASPHALT CONSTRUCTION FOR PAVEMENTS AND HIGHWAYS

CHAPTER I

INTRODUCTORY

The design and construction of a sheet asphalt pavement involve three considerations, the foundation, the intermediate or binder course, and the surface or wearing course. The same elements must be considered, although sometimes in a rather different way, in the construction of an asphaltic road surface of broken stone or of a graded mineral aggregate.

The municipal or highway engineer will provide a specification under which the construction work will be done by the contractor. This will be based, generally, upon past experience and on the results of successful service tests. In drafting such a specification the engineer should not be guided blindly by so-called standard specifications which are only of general application, nor should he, unless a person of very wide experience, depart too widely from them. Each specification should be so drawn as to apply to the individual case, to the particular environment where the work is to be constructed, and to the traffic to be met. It is useless to specify something which will call for the most perfect and most expensive form of construction where a cheaper

one will prove satisfactory, and it is equally so to provide for a cheap form of construction where the highest type is necessary, and eventually will prove the most economical. A pavement which may originally cost $2.25 per square yard may eventually prove more economical than one costing but $1.75 per square yard if the former wears fifteen years and the latter but ten, aside from the increased cost of maintenance of the cheaper form of surface. This consideration applies equally well to highway construction and to sheet asphalt pavements. Economy in first cost, therefore, is no indication of the eventual saving of money, either to the municipality, the state, or the contractor. For the same reason both engineers and contractors should give careful attention in the first instance, to the character of all materials which are available for use in the construction of a street or road surface, not only from a financial point of view, but with due regard to the reputation of the individual for doing good work. Eventual success, both structural and financial, will depend upon careful consideration of these matters.

The contractor should be possessed of sufficient information, experience and intelligence to interpret the specifications under which he proposes to work, and of good judgment to carry them out in a way to redound to his profit and reputation. The longer that the paving or road contractor has been in the business, the more he will appreciate the benefit and necessity of selecting the best materials, those which have been proved by experience to give the best results, and of organizing a force which will work with such care, based upon knowledge and experience, as will yield the best results. Of course, the contractor can use

only the specific materials which are called for, and naturally he must use the cheapest form of each which is permitted; but where there is any choice and financial considerations allow, he will never go wrong in choosing the best which are available, and of a kind which extended experience and service tests have proved to be the most satisfactory, at least, if he intends to establish a high reputation and remain in business successfully for many years.

The instructions to be given in the following pages will be based on these premises. They have been derived from observations and from the experience of the writer extending over thirty-five years, beginning in 1878 with the original Trinidad sheet asphalt surface laid on Pennsylvania Avenue in Washington, D. C., in 1876 and the extraordinary surface laid in 1879 on Vermont Avenue in that city, which is still in existence to-day. To him this fact is convincing evidence of the lasting qualities of natural asphalt when satisfactorily manipulated, either by chance, or, as is now the case, by rational methods.

Until 1894 sheet asphalt pavements were laid on empirical lines without any definite recognition of what sand grading was necessary for success, why finely ground mineral matter was added to the surface mixture or of the relations of asphalt cement to the combination of sand and dust, which is known as the mineral aggregate. A vast area of sheet asphalt surface had been constructed in cities where the travel at that time was not excessive, and where the greatest demands for stability were not made upon a surface of this type.

In 1894 the writer was engaged to supervise the introduction of the sheet asphalt pavement of the American

type in London, England. It was found that it was impossible to construct one in that city, where the traffic was heavy and the surface moist for months at a time during the winter, which would meet these conditions satisfactorily by following the methods which had previously been in use in the United States. A careful study of the subject was plainly necessary and was undertaken with a view of determining what were the essential principles which must necessarily be followed to produce a sheet asphalt surface that would resist the most trying conditions. The problem was solved in the next two years in a way which permitted the construction of pavements, subjected to heavy travel and continued moisture as in London, which have met every demand imposed upon them. In fact, the pavement so laid on Fifth Avenue, New York, proved satisfactory after fifteen years of use.

It is proposed in this handbook to give in detail a statement of the procedure which must be followed in order to duplicate such construction at the present time, in a form which will make it available to the engineer and to the contractor who have not had the widest experience in this direction in the past, and which will enable them to control the use of standard materials in such a way that they may not be discredited, as it must be recognized that in unskillful hands the best materials may prove unsatisfactory.

CHAPTER II

BROKEN STONE

Broken stone is an important element in the construction of a concrete foundation for all pavements, of the binder or intermediate course of sheet asphalt pavements, as a component of asphaltic concrete, and in asphaltic broken-stone surfaces for country highways.

Stone for any of these purposes should be derived from a hard rock, preferably a trap or hard, not coarsely crystalline, limestone. It should yield fragments, on being crushed, of satisfactory shape and fracture. The fragments should not be of a spally nature, that is to say, not thin and flat, but should be as nearly as possible cubical. Rocks of various origin behave differently in crushers, and in consequence the production of good broken stone is dependent upon very many conditions, connected not only with the stone which is the source of supply of this material, but upon the manner in which the crushing is done. As an illustration of the method by which crushed trap-rock has been made on the Hudson, the following details may be of interest.

Stone from a No. 8 Gates crusher was passed over an initial screen 15 ft. long with 2 1/8-in. holes to produce 1 1/2-in. stone, the pitch of the screen being 1 in. to the foot. The tailings, of course, went back to a smaller crusher No. 5 and the material from this crusher was passed over a secondary screen 20 ft. long, with 3 ft. of 1 3/8-in. holes, and 11 ft. of 1 1/4-in. holes for the pro-

duction of 3/4-in. or binder stone. There were also 6 ft. of 2 1/8-in. holes for 1 1/2-in. stone. The screen was jacketed with a dust jacket 7 ft. long perforated with 5/8-in. holes to remove the stone and dust passing apertures of this size. The pitch of this screen was the same, 1 in. to the foot. With the demand for clean stone of 3/8-in. size for the surface of asphaltic broken-stone roads the dust was removed from material passing 5/8-in. holes with an 8 mesh to the inch screen.

With screens of this description broken stone is produced for hydraulic concrete and for use in the wearing surface of asphaltic broken-stone roads. The 3/4-in. stone is suitable for use in binder, and for asphaltic concrete. The use of the pea grit, 3/8-in. size, has already been mentioned. The screenings or dust from this can be utilized for conversion into filler by grinding in suitable mills.

For binder, trap-rock and limestone, if the latter is hard, are equally suitable, and the same is true of stone of pea-grit size used for grit mixtures. For asphaltic broken-stone surfaces the hard limestone is preferable to trap-rock, as asphalt adheres to the surface of fractured limestone better than to the glassy surface of trap-rock.

In some cases the run of crusher, that is to say, broken stone consisting of all sizes, after the removal of the coarser material not passing the 2 1/8-in. holes and of the fine dust, has been used for the construction of asphaltic broken-stone roads and for asphaltic concrete. The difficulty with such material is that it segregates during transportation or handling at the plant, the smaller sizes separating from the larger, but with it successful asphaltic concrete has been prepared, with the addition of sand, when necessary.

Stone, other than trap-rock or hard limestone, should not be used for asphaltic surfaces with the expectation of obtaining the best results. A less satisfactory stone, a granite or field stone, may be used in the binder or intermediate course, without danger, owing to the protection which it will have from the surface coat.

CHAPTER III

FOUNDATION

A city pavement or a country road surface is of little value unless it is adequately supported, and for this it must depend upon its foundation. The latter in reality carries the load which is imposed upon the pavement or road, while the surface merely serves as a means of transmitting it to the foundation. The extent to which a pavement or highway will prove durable will depend, therefore, on the adequacy of its foundation. It must be, further, remembered that the foundation itself is placed upon the soil, and supported by it. The soil, therefore, should either be adequate for this purpose in itself or should be made so by drainage or the removal of soft material. This necessity is taken up by the writer in greater detail in "The Modern Asphalt Pavement," Chapter I.

As the foundation is an essential feature, and one of the most important ones, in the construction of a durable pavement or highway surface, both the engineer in his specifications and the contractor in his construction work, should see that it is adequately provided for, and properly constructed. The most satisfactory foundation for any form of highway surface, including both city streets, and country roads, is one of hydraulic concrete of sufficient thickness. In view of the increased weight and number of vehicles which are using our streets and the

many roads which are main arteries of travel, the necessary thickness should be provided.

It will be impossible to avoid the construction of such foundations in the future for important work, and this is the less to be regretted since, when properly built, they are durable and will last for many years, the surfaces which they sustain being renewed from time to time. They can be written up as capital and can be properly financed by long-term bond issues.

The thickness of hydraulic concrete necessary will vary under different circumstances. It has usually been 6 in. for sheet asphalt pavements carrying the heaviest traffic, which is at times reduced to 4 in. on residence streets. Such a thickness will not be found sufficient, according to the writer's idea, to carry the travel which is promised in the future, either on such streets or on some of our country highways. With the advent of the motor truck, the traction engine and the motor omnibus English engineers have arrived at the conclusion that not less than 9 in. of concrete will be required to furnish a satisfactory support. Such a thickness will be eventually demanded in the United States because in the area included in a radius of 30 miles or more about our own large cities motor trucking is becoming common, with loads amounting frequently to 10 tons.

It is not necessary in this place to offer a treatise on modern methods of concrete construction. It is important, however, to call attention to the necessity of careful consideration of the character of the sand which is to be used. Sands which appear to be satisfactory are frequently not so, and their character can only be determined by testing them with the Portland cement to be used in the work. No sand should be employed which

does not give a tensile strength, with the Portland cement selected, of at least 80 per cent. of that obtained with it with standard Ottawa sand. In the best practice it will also be found advisable to select that Portland cement among those which are available, which will give the best results with the local sand, as it has been found that cements differ largely in this respect, one brand in some cases working more successfully than another. This has been demonstrated on several occasions, especially where the work is done at low atmospheric temperatures. This is a matter, however, more for the regulation of the municipal or state engineer than for the contractor. It is not given, at the present time, as much consideration as it should be. With the cement, sand and broken stone selected for the concrete, attention must be given to the manner in which these are combined and placed upon the street. To-day the mixing is usually done by power mixers, which produce a more thorough mixture than is possible with hand labor and more economically. The condition which demands the most careful control, especially in some forms of mixers, is the regulation of the percentage of water which the mixed concrete contains; if it is too dry it will not ram or set well, but an excess of water will permit the ready segregation of the different-sized particles. A recent writer[1] on concrete has stated the case very well, as follows:

"When fine and coarse particles are suspended in a liquid the coarse, by virtue of their greater weight compared with their surface, tend to work toward the bottom, displacing the fine matter upward; for it must be remembered that a body falling through a liquid always generates an upward current

[1] Dr. J. S. Owens, The "Surveyor," Feb. 7, 1913.

to fill the space which it occupied, and this is sufficient to keep very fine particles suspended. The case of immediate interest is that of concrete mixed with too much water; in such, when kept in a state of disturbance by ramming, there is a tendency for the coarse part of the aggregate to work toward the bottom, the finer sand and cement toward the top giving a deceptive appearance to the concrete of having been thoroughly consolidated."

For the above reasons given by Dr. Owens, the concrete after having been placed on the street should not be rammed too long, especially if it is very wet.

Instead of using broken stone as the coarse portion of the mineral aggregate of a hydraulic concrete, gravel, or a mixture of broken stone and gravel may be employed. Clean screened gravel alone makes excellent concrete if the components are properly proportioned. The voids in the gravel should be determined and the amount of Portland cement mortar necessary to slightly more than fill them calculated, but the gravel should not be used in any empirical proportions, such as 1:3:6; the proportions must be determined for each gravel, and will depend upon its grading. Where gravel which is the run of the bank is used, the amount of fine material which plays the rôle of sand must be determined and allowed for, and satisfactory results are only obtained when due consideration is given to this and the mineral aggregate is properly proportioned. Mixtures of broken stone and gravel, where the size of the latter is suitable for filling the voids in the stone, make a very satisfactory concrete, as an example of which the foundation under the Fifth Avenue pavement in New York, which was laid in 1896–7, may serve. The presence of gravel in the voids in the broken stone reduces the volume of Portland cement

mortar which is necessary, and at the same time facilitates the putting of the material in place by ramming.

The manner in which the surface of a Portland cement concrete foundation for sheet asphalt pavements is finished demands some consideration. It has usually been thought that this should be left in a rough condition, with fragments of stone projecting above the surface of the mortar, and this procedure has even gone so far as to imbed sharp fragments of stone in the mortar before it is set. In the writer's opinion, this is a serious mistake. There are good reasons why the surface should be made as smooth as possible, and even floated with mortar, as is done in Great Britain and on the Continent, namely, that where it is not smooth and where stone projects, the thickness of the bituminous courses, binder and surface, differs at different points. In compressing these courses the roller will ride over the lowest portions of the foundation and the compression at these points will be less than elsewhere. Under travel those portions of the pavement which have not received complete compression under the roller will be compressed by it to an additional extent, thus permitting the formation of surface depressions which may be the cause of subsequent displacement due to the impact of the wheels of vehicles. The irregularity and waviness of many bituminous pavements is, undoubtedly, to be attributed to such a cause. The writer, therefore, advocates a smooth finish with concrete foundation for any form of bituminous surface.

Foundations other than concrete are frequently used for sheet asphalt pavements, and for bituminous road surfaces, very often in both instances, old, water-bound, broken-stone roads. Where such a surface is on firm soil and has been subjected to travel for many years, it

has frequently proved most satisfactory, as for example, on Broadway above 59th Street, New York City, where a sheet asphalt pavement has been satisfactorily maintained for many years on an old broken stone surface, and is only now being slowly replaced as new surfaces are constructed. On country highways it has frequently been successful, although not always so, especially where there is lack of drainage. In constructing a bituminous broken-stone road in the country care should be taken that drainage is supplied at all points where there is any accumulation of water or a clay bottom, which is liable to be thrown out of place by frost.

A striking example of the suitability of an old water-bound broken-stone road as a foundation for a bituminous pavement, is seen on the Victoria Embankment in London. This roadway in 1906 consisted of a great depth of water-bound broken stone accumulated during a long period of years, the thickness being due to the continued application of broken stone in attempts to maintain the surface. It had an extremely high crown or camber. With the advent of motor traffic on the Embankment, the surface was found to be entirely inadequate to meet the conditions imposed upon it, and trials were made of numerous forms of bituminous pavements to overcome the difficulty. Among these was a sheet asphalt surface placed upon 3 in. of asphaltic concrete upon the old broken stone, after it had been graded to the proper contour. This form of construction has now been in place, in certain portions, for seven years, and the foundation has proved to be entirely adequate to support the asphalt concrete binder and the surface placed thereon under the heavy travel which the roadway carries.

Old brick pavements which are worn and have a rough surface form an excellent foundation for sheet asphalt pavements, and the same may be said of Portland cement concrete surfaces. On this account, where pavements of these types are constructed, they should originally be laid at such a grade, as to permit of the addition of a bituminous surface when the original one becomes unsatisfactory.

In the early days of the sheet-asphalt paving industry a so-called bituminous foundation consisting of a coarse broken stone, bound to a certain extent with some form of bituminous material, was in use, but this has been entirely abandoned in good practice, as it possessed no rigidity, and for the same reason it should be abandoned on country highways. In addition it is very difficult to remove an old surface from such a foundation, and to replace it with a new one, owing to the adhesion of the one to the other.

To-day in the construction of country highways the foundation, if it may be called such, is really an intermediate course, consisting of broken stone of a size larger than that in use in the wearing surface, the fragments being as much as 2 1/2 in. in diameter. This is in itself supported only by the sub-soil and, especially on poor soils, where the travel is heavy, it is a quite inadequate and eventually a very expensive form of construction, as much of the stone is lost by being compressed into the soil. Such a course, except on the most stable soil, frequently becomes of little value, being displaced under heavy travel.

It is frequently provided that the lower course of broken stone shall be covered with a filler of fine material but, according to the writer's idea, this is a great mis-

take, since the fine particles act as a lubricator to facilitate the movement of the coarse broken stone and, when driven into the mass by travel or settlement force the stone apart and prevent the proper bearing of the fragments on one another, depriving the course in consequence of its greatest stability. Fine material, in addition, possesses a capillary action and holds water, which is undesirable. A course of clean broken stone offers much better drainage.

It cannot be too strongly reiterated here, that in the construction of any form of pavement or highway, provision should be made for the prompt removal of water from the foundation, and also from any possible action on the intermediate course or surface, as there is no greater enemy to durability in any form of highway construction, than water.

CHAPTER IV

THE INTERMEDIATE COURSE

Sheet Asphalt Pavements.—In the early days of the construction of sheet asphalt pavements, no intermediate or binder course of stone was used between the foundation and the surface, but it was soon found that greater stability was obtained in the surface if it was provided for. In the thicker surfaces which were originally used there was great liability to displacement under travel, making the surface uneven, wavy and unpleasant to ride over. An intermediate or binder course was first introduced into the sheet asphalt pavement industry in Washington in 1888, for the reasons given and its use has, since that time, become general. For a period of nearly twenty years it consisted of a course of broken stone 3/4 to 1 in. in largest diameter, coated with bituminous material and compressed under a roller. Within the last ten years an asphaltic concrete, consisting of a mineral aggregate of properly proportioned broken stone and sand, with an asphalt cement as a cementing material, has, on the suggestion of the writer, replaced the simple broken-stone binder originally used. These two forms of intermediate course are known respectively as open and close binder.

Open Binder.—Open binder consists of stones largely of one size, the fragments being from 3/4 to 1 in. in their largest diameter, although at times run of crusher has been used. Broken stone of the latter description requires a larger amount of bituminous cementing

material, and in consequence the binder is more cohesive. The following data will show the average composition of open binders which have been used at different times in the construction of sheet asphalt pavements.

It appears from these figures that the percentage of bitumen which a binder requires depends largely upon the amount of fine material which it contains. The first mentioned in the table contains 26.8 per cent. of fine material and requires 5.4 per cent. of bitumen, while those made from cleaner stone where the fine particles do not exceed 5 per cent., contain less than 4 per cent. of bitumen. In preparing, sending to the street, and placing a course of open binder, care is demanded in certain directions. The stone should be hard, sufficiently so not to crush under the roller. It should be free from clay and dirt, although as has been said, fine particles of the stone itself are an advantage rather than otherwise. In heating the stone and mixing it with the asphalt cement, great care should be used that it is not overheated, since if this is the case a proper coating of the bonding material will not adhere to the stone, owing to the excessive heat, or much of it may run off and be lost during the haul to the street. On the other hand, the binder should be hot enough to permit of properly coating it and its ready compression on the foundation. An open binder should be bright and glossy, and not dead in appearance, as it is dumped from the truck. It should be hot enough to spread readily and uniformly. It should contain no excess of bitumen at any one spot, and should this be the case, such spots should be removed and replaced. Binder after it has been placed on the street or road, should be covered within the shortest space of time possible with the sur-

AVERAGE COMPOSITION OF OPEN BINDERS USED IN SHEET ASPHALT PAVEMENTS

Test No.	69978		70804		70854		71102		74893	
Bitumen	5.4%		4.4%		3.8%		3.6%		3.5%	
Filler	5.8	26.8	4.1	16.6	2.2	9.7	2.4	5.4	1.5	4.5
Sand	21.0		12.5		7.5		3.0		3.0	
Stone:										
Passing 1/4-in. sieve	5.8	67.8	8.7	79.0	18.0	86.5	13.5	91.0	49.5	92.0
Passing 1/2-in. sieve	13.6		46.8		52.0		51.5		10.0	
Passing 1-in. sieve	41.4		23.5		16.5		26.0		32.5	
Retained 1-in. sieve	7.0		0.0		0.0		0.0		0.0	
	100.0		100.0		100.0		100.0		100.0	

face, as when it has been wet, tracked with dirt, or become covered with horse-droppings or dead leaves, the adhesion of the surface mixture to it will not be complete.

In actual practice a 9 cu. ft. box of broken stone for binder which will weigh about 900 lbs. will require about 40 lb. of Trinidad and about 36 lb. of Bermudez asphalt cement, but the cement must be regulated by observing the appearance of the material in the truck and on the street.

In preparing a binder at the plant the mixer in use should have teeth with a sufficient clearance between them and the lining of the mixer so that the largest particles of stone cannot become wedged between them, and thus rapidly wear out the lining of the mixer. It is not good practice to attempt to mix binder in the same mixer that is employed for preparing the surface mixture. A separate one should be employed, although in some of the smaller plants of a portable description, it is not always possible to do so, in which case provision must be made for making a change of teeth from the longer to a shorter form, in changing from surface to binder mixing.

Close Binder.—Close binder is, or should be, a true asphaltic concrete. It consists of the same broken stone of which the open binder is made, but the voids in it are filled with smaller stone and with an asphaltic mortar corresponding to the ordinary asphalt surface mixture. For the construction of a close binder or asphaltic concrete of the highest type, the grading of the mineral aggregate should be carefully regulated. This can be done by determining the voids in the coarser stone, calculating the amount of fine stone necessary to fill these, and again the amount of sand to fill those in the mixture of coarse and fine stone. This can be readily

done by constructing a box of sheet-iron or wood of exactly 1 cu. ft. capacity. It is filled with the hot coarse stone which is compacted by shaking. The surface is then struck off and the box weighed. Allowing for tare, the weight of 1 cu. ft. of the coarse stone is obtained. Knowing the density of this stone, 2.65 for limestone and 2.9 to 3.0 for trap-rock, the weight of a solid cubic foot of the stone can be calculated. By dividing the weight of a cubic foot of the broken stone by the weight of a solid cubic foot of the material, the voids can be determined. In the same way the weight of a cubic foot of the finer stone and of the sand can be arrived at. One can readily calculate the amount of each which it is necessary to use to fill the voids in the coarse stone, and again in the mixture of the coarse and fine stone. The proportions for actual use can be readily determined and the amount of bitumen required from the percentages of broken stone and sand that are present.

As an example of the proportions of coarse stone, fine stone, sand and asphalt cement in actual use in preparing a close binder, the following figures will serve:

	New York		Boston
	Plant 1	Plant 2	
Coarse stone......	480 lb. = 54.6 %	480 lb. = 53.3 %	
Fine stone........	200 lb. = 22.7	202 lb. = 22.4	885 lb. = 73.4 %
Sand............	150 lb. = 17.0	150 lb. = 16.7	250 lb. = 20.8
Trinidad asphalt cement.	....	68 lb. = 7.6	70 lb. = 5.8
Bermudez asphalt cement.	50 lb. = 5.7	....	....
	880 lb. = 100.0	900 lb. = 100.0	1,205 lb. = 100.0

ANALYSES

Bitumen soluble in CS_2	5.6%		5.2%		4.8%	
Passing 200-mesh screen	4.4		6.4		4.2	
Passing 10-mesh screen	29.2	33.6	29.0	35.4	26.4	30.6
Passing 8-mesh screen	1.8		2.0		.8	
Passing 1/4-in. screen	10.0		7.0		4.4	
Passing 1/2-in. screen	23.2		25.8		24.4	
Passing 3/4-in. screen	13.6		17.8		32.2	
Passing 1-in. screen	7.4		6.8		2.8	
Retained 1-in. screen	4.8		0.0		0.0	
	100.0		100.0		100.0	

At some plants it is impossible to separate the stone into coarse and fine particles, in which case the heated stone of both sizes is collected in one bin, but segregation generally occurs under such circumstances. In arranging the grading of the mineral aggregate care should be taken to see that the amount of fine material, while sufficient to fill the voids in the stone, is not present in excess, since in this case the surface of the binder when compacted on the street will be too smooth to bond properly with the wearing surface, and resulting displacement under travel will be possible. An excess of bitumen must also be avoided for the same reason, and if spots in the binder as laid show anything of this description, the material should be removed.

An entirely satisfactory close binder can be constructed for all but the most trying conditions by the use of selected old surface material, which has been disintegrated and softened by steam, for filling the voids in the ordinary open binder. It is, of course, a matter of great economy to turn out a close binder in this manner. The old surface material having been crushed and softened by dry steam, is added in the mixer to the hot binder stone and, in this manner, further disinte-

grated and distributed among the stone. The proper amount of additional asphalt cement is added to coat the stone and enrich the old surface mixture. It does not possess the complete stability of an asphaltic concrete but it is infinitely superior to the ordinary open binder for the construction of an intermediate course.

The asphalt cement in use in binder may well be considerably softer, ten to fifteen points, when it is possible to make it so, than that in use in the sheet asphalt surface.

In the construction of asphalt pavements with an asphaltic concrete binder course, the surface should be applied to it before it has become entirely cold. It is well to run out binder to the street for not more than half of a working day and to cover it with surface during the same day. This is much more important with a close than with an open binder. It is not possible to do satisfactory work where a large area of close binder is laid on one day and covered with surface on the next.

Asphaltic Concrete as a Wearing Surface.—It is becoming more frequent to construct the wearing surface of a pavement with asphaltic concrete. In that case there is, of course, no intermediate course. The grading of the mineral aggregate of an asphaltic concrete for surfaces is a more important matter than when it is used as a binder and protected by a sheet asphalt surface. It requires, in order that it may have the greatest durability, the use of a certain amount of filler, that is to say, the finer portions of the concrete should be as carefully graded as an ordinary sheet asphalt mixture.

In many cases, as in Washington, D. C., successful surfaces for moderate travel have been laid by combining the ordinary sheet asphalt surface mixture with the open

binder composed of run of crusher stone, which are so proportioned that the sheet asphalt mixture exactly or slightly more than fills the voids in the stone. Such a mixture, laid on 13th Street in that city in 1910, had the following characteristics:

ASPHALTIC CONCRETE LAID ON 13TH STREET, WASHINGTON, D. C., 1910

Test No.	117,967		117,968	
Bitumen	7.8%		7.5%	
Passing 200 mesh	2.7	32.7	1.6	27.9
Passing 10 mesh	30.0		26.3	
Passing 8 mesh	.8	4.6	.6	3.6
Passing ¼-in. holes	3.8		3.0	
Passing ½-in. holes	14.0	54.9	12.4	61.0
Passing ¾-in. holes	22.5		17.0	
Passing 1-in. holes	11.4		17.4	
Retained 1-in. holes	7.0		14.2	
	100.0		100.0	
Specific gravity, sand	2.65		2.65	
Specific gravity, stone	2.91		2.91	
Specific gravity, mineral aggregate	2.816		2.826	
Voids in mineral aggregate	17.8%		24.8%	

The above mixtures have proved very satisfactory under the environment to which they have been exposed. They are plainly deficient in filler and their lasting properties would be increased if more had been used.

Asphaltic Broken Stone and Asphaltic Concrete Country Highways.—These types of surfaces are seldom supported upon an intermediate course, unless the course of large broken stone on which the bituminous surface is placed in the case of asphaltic broken-stone roads, may be considered as such rather than as a foundation. Asphaltic concrete is usually placed directly upon an old macadam or upon a Portland cement concrete foundation. More will be said of these surfaces in subsequent pages.

CHAPTER V

THE MINERAL AGGREGATE

Sheet Asphalt Surfaces.—Sheet asphalt surfaces are constructed to carry the travel upon the street or road and transmit the load or burden to the foundation. They are intended to withstand wear and tear and the action of the elements. They consist of a mineral aggregate of sand, at times some fine stone, filler of impalpably fine ground mineral matter and an asphalt cement. The whole may be looked upon as an asphalt mortar, or where broken stone is present to the extent of 50 per cent. or more, as an asphaltic concrete.

The character of the mineral aggregate, since it forms at least 90 per cent. of the pavement, is one of the most important things to be considered, and the greatest care should be taken in choosing the material of which it is made up. In a sheet asphalt pavement of the ordinary type, sand forms at least 80 per cent. of the mineral aggregate, the remainder consisting of filler and asphalt cement.

SAND

In the early days of the asphalt paving industry the suitability of the sand for the purpose was given little attention, any sand locally available being used without particular regard to its grading, that is to say, the relative proportion of grains of different sizes of which it is made up. Too often a sand which would make a good cement mortar was considered suitable for the purpose. In

the course of years it was demonstrated that some sheet asphalt pavements were infinitely superior to others in durability. With a view of determining to what this was to be attributed, specimens of surfaces which had withstood service tests well and poorly were collected by the writer as long ago as 1894 and the character of the mineral aggregate determined in the laboratory. In the case of two exceptional pavements, one laid on Vermont Avenue between "H" and "I" Streets in Washington, D. C., in 1879, which is still in existence and in satisfactory condition, and another of excellent character on Court Street in Boston, the surfaces were found to have been made with fine sand, while those surfaces which had behaved badly in different parts of the country consisted largely of coarse sand with a great deficiency in fine grains and filler. This made it evident that the character of the sand is a very important consideration, and that its grading must be carefully considered. The character of sand can be determined by separating it into particles of different sizes by means of sieves. The sieves which are conventionally used for this purpose consist of a series of screens of woven wire cloth of different sized wire and openings or meshes between the wires of 200, 100, 80, 50, 40, 30, 20, and 10 meshes to the lineal inch. The size of the particles which these screens pass bear a numerical ratio to each other. Such sieves are now made with great care and are standardized by the U. S. Bureau of Standards at Washington. By their use the exact grading or character of any available supply can be determined. As an example the following data in regard to a very desirable sand in use in Philadelphia and a very undesirable river sand from the Ohio River at Louisville, may be given.

	Philadelphia 1905	Philadelphia 1912
Passing 200 mesh	0%	1.9%
Passing 100 mesh	22	12.6
Passing 80 mesh	18	16.5
Passing 50 mesh	30	35.3
Passing 40 mesh	14	6.2
Passing 30 mesh	7	12.5
Passing 20 mesh	5	6.8
Passing 10 mesh	4	8.2
Retained 10 mesh	0	2.0
	100.0	100.0

	Louisville—River
Passing 200 mesh	2%
Passing 100 mesh	1
Passing 80 mesh	4
Passing 50 mesh	53
Passing 40 mesh	25
Passing 30 mesh	10
Passing 20 mesh	3
Passing 10 mesh	2
	100%

The satisfactory Philadelphia sand, it will be observed, contains, in one year, 40 per cent. and in another 29 per cent. of grains of 100- and 80-mesh size. The unsatisfactory sand contains but 5 per cent. of such sized grains and, on this account, would be unsuited for use by itself in constructing a durable sheet asphalt pavement. It is evident, therefore, that in preparing for the construction of a sheet asphalt pavement in any locality the first thing to determine is whether a satisfactory sand supply is available, and this can only be done by the collection of samples and their examination with the sieves which have been mentioned. It will appear, later on, in the consideration of the surface mixture as a whole, that in determining the characteristics of the sand the essential features are that it shall contain sufficient material of the size passing 100- and 80-mesh screens, not too large an amount of coarse grains passing sieves of 30, 20 and 10 meshes to the inch, that is to say, material retained on a 40-mesh screen, and a very small amount of material passing a 200-mesh screen. The last is found to be undesirable and does not contribute stability to the surface mixture, unless it is entirely of the nature of a filler, in which case much of it will be blown away on passing through the sand drums on heating. For this reason, for ordinary purposes, a sand may be examined more simply with three sieves, determining the amount passing a 200-mesh screen, that passing an 80 but retained on a 200-mesh and the amount remaining on a 40-mesh screen.

As a result of extended experience a sand which will be satisfactory for the construction of the most durable type of sheet asphalt pavement, to withstand heavy travel, should average as nearly as possible to the grading given

below. For less important work and lighter travel sands containing a smaller amount of fine material may be used, and the grading of such a possible material is also given.

	Heavy Traffic		Light Traffic
200 mesh.			
100 mesh...........	17.0%	34.0	26.0%
80 mesh...........	17.0		
50 mesh...........	30.0		30.0
40 mesh...........	13.0		13.0
30 mesh...........	10.0	23.0	30.0
20 mesh...........	8.0		
10 mesh...........	5.0		
	100.0		

It sometimes occurs that no single local supply furnishes a sand which will correspond to this grading. In such a case it may be necessary to combine two or three sands to accomplish the desired result, or it may prove cheaper to do this than to use a single expensive source of supply. As an example of this may be cited the necessity for mixing two sands in arranging the mineral aggregate for the sheet asphalt surface laid on Fifth Avenue in New York in 1896–97. The local supply of sand sifted as follows:

Passing 200 mesh	2 per cent.
100 mesh	6 per cent.
80 mesh	9 per cent.
50 mesh	25 per cent.
40 mesh	26 per cent.
30 mesh	14 per cent.
20 mesh	10 per cent.
10 mesh	8 per cent.
	100 per cent.

This contained but a total of 17 per cent. of material passing the 200-, 100-, and 80-mesh screens, which is a decided deficiency. It was, therefore, mixed with a finer sand coming as ballast from South Africa, which sifted as follows:

Passing 200 mesh	6 per cent.
100 mesh	13 per cent.
80 mesh	29 per cent.
50 mesh	35 per cent.
40 mesh	9 per cent.
30 mesh	5 per cent.
20 mesh	2 per cent.
10 mesh	1 per cent.
	100 per cent.

The combination of the two in the proportion of 2/3 coarse to 1/3 fine sand resulted in a more satisfactory grading, as will be seen by calculating the result. The *mixture* would be as follows:

Passing	200 mesh	3 per cent.
	100 mesh	8 per cent.
	80 mesh	16 per cent.
	50 mesh	29 per cent.
	40 mesh	20 per cent.
	30 mesh	11 per cent.
	20 mesh	7 per cent.
	10 mesh	6 per cent.
		100 per cent.

The resulting surface mixture made with the sand when combined with filler and asphalt cement will be discussed in another chapter.

The necessity for the presence of a certain amount of particles passing a 100- and an 80-mesh screen, is a double one. Some material of this nature is required to produce a surface mixture which shall close up tightly under rolling and thus exclude water. It reduces the size, and to a certain extent, the volume of the voids between the larger sand particles which must be filled with asphalt cement and, in this sense, adds to the stability of the mixture to a certain degree, as also does the finer material or filler which is employed in addition. The 100- and the 80-mesh particles are necessary to permit of the use of a sufficiently large percentage of filler to further accomplish this result and give stability to the mineral aggregate and to the asphalt cement. Unless the sand contains a large percentage of fine particles of 80- and 100-mesh size the filler which is added, if in sufficiently large amount to make the most desirable surface, will accumulate in balls and adhere to the coarser particles of sand in an irregular way, making it difficult *or impossible* to spread and compress the hot

material on the street satisfactorily. It will be observed, in another chapter, as illustrating this fact, that a mixture such as that laid on the Thames Embankment in London, which carries 17 or 18 per cent. of particles passing a 200-mesh sieve, largely filler, contains at the same time 30 per cent. of fine, 100- and 80-mesh, sand particles. Without the presence of the latter it would be impossible to use the amount of filler employed. It is found also that unless the percentage of filler is large the percentage of bitumen in the mixture cannot be carried at a high figure, as should be the case to enable the pavement to resist moisture. The importance of the sand grading is, therefore, plainly indicated.

The character of the material composing the sand grains is, of course, a matter of importance. It should consist of hard quartz. The character of the surface of the grains cannot be neglected. It should be free from any adhesive ferruginous or argillaceous matter which would prevent the proper adhesion of the asphalt cement, that is to say, the sand should be clean. Even with clean sand grains there is a difference in the sand's behavior with bitumen, which may be compared to that of the surface of an ordinary sheet of glass and one of ground glass. The latter will hold a coating of bitumen well, and the other less satisfactorily, as can be easily understood. As a matter of fact sands from certain localities will carry less than 9 per cent. of bitumen, whereas others, as those on the Pacific coast and in England, will carry over 11 per cent. The behavior of every sand in this respect can only be determined by trial.

The shape of the sand grains has also a direct effect upon the character of the surface mixture. Too sharp a grain is not desirable and, on the other hand, one that

is too round and resembles shot is more so because it is unstable. A medium sharp grain is desirable but the preference lies for the rounded grain rather than a sharp one, as the rounded grain produces a surface mixture which is more readily compressed on the street.

Sands and their characteristics are discussed at great length in the writer's book "The Modern Asphalt Pavement," and it is important that every one engaged in the construction of sheet asphalt pavements should be thoroughly familiar with this subject in order to be able to make a proper selection of material of this description, for good work.

Aggregates Containing Fine Stone.—Aggregates of the type of which asphalt blocks are composed consist of an admixture to the fine material of small broken stone or pea grit. Aggregates of this description are also employed for monolithic sheet work, and have become quite popular within the year 1912, having been constructed on a large scale. It is improper to call these, as is sometimes done, asphaltic concrete, as the stone is too small both in size and amount, to make it possible to regard the aggregate as concrete. The stone should constitute more than 50 per cent. of an aggregate, in order that it may be classed as a true concrete. The composition of an asphalt block will average about as follows:

Density of block........	2.53
Bitumen...............	7.3
Passing 200 mesh........	16.7
Passing 10 mesh........	39.5
Passing 8 mesh........	7.0
Passing 1/4-in holes.....	26.5
Retained 1/4-in. holes...	3.0
	100.0 per cent.

It appears that this aggregate consists to a large extent of particles of the size of sand and filler and about 30 per cent. of pieces of stone retained on an 8-mesh screen, approximately 1/4 in. in diameter. Such an aggregate is typical of a grit mixture. Of the character of such mixtures when combined with bitumen and laid in monolithic form more will be said in another place.

CHAPTER VI

FILLER OR DUST

An impalpably finely ground mineral matter or dust is used as a filler in combination with sand to complete the mineral aggregate for surface mixtures in order to make the surface when compressed more dense, and to render the asphalt cement, which is one of the components, more stable and less susceptible to the high temperatures to which it may be subjected under the summer suns of our climate. It makes the surface, at the same time, less susceptible to water action, and less liable to displacement under travel. It is an important part of the mineral aggregate for many reasons, as giving it stability and, as shown by the writer's examination in the early years of the industry of the surfaces which proved to be satisfactory, it was the presence of a proper percentage of such material, in addition to the character of the sand, which made them so.

In any filler it is the amount of material which is so impalpably fine as not only to pass a 200-mesh sieve but also to remain suspended in water for at least fifteen seconds, which is of value. The 200-mesh screen alone will not demonstrate its value. Anything which is so coarse as to simply pass the 200-mesh screen, will merely play the rôle of sand, and will be a poor sand at that. A material to be suitable for a filler should be ground so fine that at least 75 per cent. will pass a 200-mesh sieve and at least 66 per cent. of it remain suspended in water

of a definite temperature for fifteen seconds. These characteristics may be readily determined in the laboratory. Illustrating the conditions in various supplies of fillers the following data will serve:

Test No.	75803	75804	75805	75806	71076	75791
Dust	Lime-stone	Trap-rock	Port. cement	Clay	Marl	Vol-canic
Passing 200 mesh	84.0%	81%	74%	93%	92%	100%
Passing 100 mesh	14.0	18	19	5	4	
Passing 80 mesh	2.0	1	6	1	2	
Passing 50 mesh	....	.....	1	1	2	
Elutriation test, not settled in 15 seconds.	71.3	70.3	56.7	87.8	80.3	98.2
Pounds per cubic foot	113.7	112.3	123.5	78.0	78.0	63.4

It appears that in materials which may be used as a filler there is a decidedly smaller proportion of impalpably fine powder than of particles which will pass a 200-mesh sieve.

Another important consideration in connection with materials in use as a filler is the volume weight of the pulverized material. In the table the data shows that this varies to a very great extent. The heavier the weight, the more desirable the filler is, as it contributes to the density of the surface mixture.

The nature of the material that the filler is derived from is of importance. It has been found by service tests that the most desirable filler is a finely ground

Portland cement, and this should always be used where the surface is to be subjected to heavy travel or to excessive moisture. The filler for ordinary use is usually a ground limestone of the desired fineness. Clay could be used as a filler were it not for the fact that it is so light as to make the loss in mixing the dry mineral aggregate excessive.

The amount of filler which is added to the sand should be such that a finished surface mixture for ordinary purposes will contain at least 10 per cent. of 200-mesh particles. It should reach 18 per cent. in surfaces made with fine sand which are to withstand the heaviest traffic and the most trying climatic conditions. As has been said previously the use of such high percentages of filler requires a sand carrying a proper amount of fine particles, to prevent the filler from segregating into balls in the hot mixture. The amount of filler in actual use will vary depending on whether the asphalt employed contains mineral matter or not. As Trinidad asphalt cement contains a percentage of clay and impalpably fine quartz acting as a natural filler it is not necessary to add as much artificial filler as in the case of Bermudez asphalt, which is a nearly pure bitumen. In turning out a Trinidad surface mixture, therefore, but 80 lb. per 9 cu. ft. box may be necessary with Trinidad for ordinary work whereas 100 lb. or more must be used with a Bermudez asphalt cement. Regard must also be given to the fact that the density of Portland cement is much greater than limestone, and a greater weight of the former material than of the latter must be used if the same volume of filler is to be provided.

Finally it should be said that upon the judicious use of filler the entire success of a sheet asphalt surface may

depend. The amount should not be reduced below the limit suggested and it can be kept at the highest figure that the sand permits to the greatest advantage. On the other hand, an excess of filler with a poorly graded sand, will make the hot mixture so tough that it cannot be easily raked out and spread on the street. On this account an adequate amount is impossible with such sands.

In turning out a close binder, filler is not as essential, since the stone gives stability to the mixture, but if an asphaltic concrete surface is being constructed, filler is essential, and should be used in such proportions that it will be present in an amount corresponding to that which would be required by the sand present, considered as an aggregate of a sheet asphalt surface mixture.

CHAPTER VII

NATIVE BITUMENS

A mineral aggregate which is above criticism being available, the character of the sheet asphalt surface which is produced, will depend upon that of the asphalt which is used as a binding or cementing material, and upon the manner in which it is manipulated.

A native bitumen is one found in nature consisting of a mixture of hydrocarbons and their derivatives, which may be gas, a liquid, a viscous liquid or a solid. If solid it melts more or less readily on the application of heat, and is soluble in turpentine, chloroform, carbon disulphide and similar solvents, as well as in the heavy petroleum oils. One of the solid forms of native bitumen is asphalt. The asphalts are characterized by various physical and chemical properties, and by their behavior when subjected to certain conditions which have been defined. The most important of these are in detail as follows:

PHYSICAL PROPERTIES

Specific gravity, 77° F. 77° F. Original substance, dry
Specific gravity, 77° F. 77° F. Pure bitumen
Color of powder or streak
Luster
Structure

Fracture
Hardness, original substance
Odor
Softens
Flows
Consistency, penetration at 77° F.
Ductility in centimeters

CHEMICAL CHARACTERISTICS

Original substance,
  Loss, 212° F., one hour
Dry substance,
  Loss 325° F., five hours
  Character of residue
  Consistency, penetration of residue at 77° F.
Bitumen soluble in carbon disulphide, air temperature
Inorganic or mineral matter
Difference
Malthenes:

  Bitumen soluble in 88° naphtha, air temperature
  This is per cent. of total bitumen
  Per cent. of soluble bitumen removed by H_2SO_4
  Per cent. of total bitumen as saturated hydrocarbons
Carbenes:
  Bitumen insoluble in carbon tetrachloride, air temperature
Bitumen yields on ignition:
  Residual coke, ash free
Sulphur
Paraffine scale
Ultimate composition

Experience and long-time service tests have demonstrated that certain native asphalts, such as those from the Trinidad and Bermudez lake deposits, have been most successfully used in the production of an asphalt cement for the construction of pavements and road surfaces, and more so than any other solid bitumens. The characteristics of these materials may be taken, therefore, as a standard. They are to be found for each of these asphalts on a subsequent page. They are, of course, somewhat modified when they are combined with a flux to produce an asphalt cement. Cement made from Trinidad and Bermudez asphalt is characterized by a definite specific gravity in each case, by a certain ductility as determined by a conventional test, by containing but little volatile matter so that when the cement is heated for some time at the temperature at which it is used the loss does not exceed a small percentage and the consistency is not reduced to an alarming degree, by the fact that it has a certain viscosity with which other asphalt cements can be compared, and that it contains a large amount of sulphur, which has an important bearing on its stability. These cements, in addition, possess adhesive binding and cementing properties and are not short, cheesy and oily. They do not harden excessively when exposed to low temperatures or become too liquid under the summer sun. They do not contain a large portion of light oils volatile during the period in which the material is maintained in a melted condition or on mixing with a hot mineral aggregate. They have great viscosity at atmospheric temperatures but become sufficiently mobile at higher temperatures to mix satisfactorily with the mineral aggregate.

Residual pitches prepared from asphaltic or semi-asphaltic petroleums by industrial processes, are generally termed asphalts, as well as the solid native bitumens, using this designation in its broadest commercial sense. Owing to the different kinds of petroleum in which they originate, they are of a very varied character, and at the same time, owing to the greater or less care with which they are prepared, they are far from uniform. As yet, it has not been demonstrated by long-time service tests that they are the equals of the solid native bitumens. Where they have been used the cost of maintenance is considerably greater than that of the native asphalts, but it must be remembered that the skill and judgment with which any asphalt is manipulated is of equal importance as its character, and the residual pitches may not have been used as skillfully as has been the case with the native material.

Trinidad asphalt, as it is well known, has been in use in the construction of sheet asphalt pavements since 1876, when it was first used on an extended scale on Pennsylvania Avenue in Washington, D. C. There are many other striking examples of the behavior and durability of this material in existence at the present time. One of them is the sheet asphalt surface, which has been mentioned on a previous page, on Vermont Avenue in Washington, D. C., between H and I Streets. This surface was constructed in 1879 and is in existence today, 1913, after thirty-four years use, and, even now, is in a condition which permits the conclusion that it will give many years further service. The maintenance in the period between the date of its construction and 1910 was only 9.98 cents per superficial square yard. Another example is the surface which was constructed on Fifth

Avenue in New York City in 1896–97, and which has withstood with great satisfaction the enormous travel to which it has been subjected on that street. On some of the business streets of Chicago subjected to the heavier commercial traffic, such as Market, Franklin and Quincy Streets, Trinidad asphalt surfaces have proved as lasting as any smooth surface pavement would have been under the same conditions. A most striking example of the ability of a well-constructed Trinidad asphalt surface to resist the severe conditions existing in the climate of England and the heavy travel of a London thoroughfare, will be seen on the Victoria Embankment in London. This surface, which is of world-wide repute, has demonstrated the fact that it has been able to meet the conditions existing at that point in competition with many other forms of construction, with entire success. It has been pronounced by an engineer of the Road Board of Great Britain to be a type of the most successful form of bituminous road surface.

The successful use of Trinidad asphalt may be attributed to the entire uniformity of the material as it is found in the so-called lake deposit in the Island of Trinidad. Every cargo of the asphalt which has been brought from that point during the last thirty-six years or more, has been found, by observation of the writer, to be practically like another. This is an extremely important feature, as, when its manipulation is once learned, there is no necessity for making changes in it to obtain uniform results. Among its other desirable properties are its stability, under which may be included its resistance to high temperatures under manipulation and permanence of consistency, its lack of susceptibility to solar radiation in the street during the summer,

and the fact that it carries, intimately mixed with it by nature, a large percentage of fine mineral matter of the most desirable character as a filler.

Bermudez asphalt is another form of native bitumen or asphalt, which is found in Venezuela. It differs from the Trinidad asphalt in carrying no admixture of mineral matter, being a nearly pure bitumen. The deposit is not as uniform as that which is found in Trinidad, and the material as dried or refined, varies from time to time in its consistency. It hardens on heating through loss of volatile oils more than the Trinidad material, and its manipulation requires greater care to produce a satisfactory asphalt cement. It possesses certain properties, however, which makes it preferable to Trinidad asphalt in that it melts to a thinner liquid owing to the absence of mineral matter, and on this account permits of easier manipulation. At the same time it lacks the stability of Trinidad asphalt and suffers more from abuse in melting and mixing with hot aggregates. Bemudez asphalt has been subjected to service tests since 1893 and when combined with a suitable mineral aggregate has given entirely satisfactory results, surfaces constructed with it being of a durable nature. It has been much used in the last four or five years as a cementing material for bituminous broken-stone highways, and has proved extremely successful as applied to this form of construction, owing to the fact that it can be used in the penetration process with much greater ease than a similar binding material made from the more viscous Trinidad asphalt, although the Trinidad asphalt is equally satisfactory, as used in New York State, when once it is properly introduced into the road surface.

The two asphalts which have been mentioned, Trinidad and Bermudez, have been tried out for such long periods of time that their reputation as a satisfactory binding material is established. None of the asphaltic materials, the products of asphaltic petroleum manipulated by industrial processes, have been tried out for the same length of time, or at least, there is no surface in existence to-day of the same age. They have not been shown to possess the durability of the native lake bitumen. For this reason, this handbook is confined to the use alone of the two materials mentioned, although of course, many of these directions can be applied to the use of other materials.

Trinidad Lake Asphalt.—Crude Trinidad asphalt is an extremely uniform mixture or emulsion of gas, water, fine sand, clay and bitumen combined in the following proportions:

Bitumen	39.3 per cent.
Mineral matter	27.2
Water of hydration of clay	3.3
Water and gas, loss at 325° F.	29.0
	98.8 per cent.

It has been found to have practically the same composition in the entire deposit, having a surface of more than 1,000 ft. in diameter and a depth of over 135 ft. In preparing it for use in the paving industry it is subjected to so-called refining which amounts really to drying the material and removing the water entering into the emulsion which composes the crude material. Some of the characteristics of the refined material are as follows:

REFINED TRINIDAD ASPHALT

PHYSICAL PROPERTIES

Specific gravity at 77° F.	1.397
Melting-point	230° F.
Color of powder or streak	Blue black.
Luster	Dull.

CHEMICAL CHARACTERISTICS

Loss at 325° F. for five hours	0.8 per cent.
Character after heating	Smooth.
Bitumen soluble in CS_2	55.8 per cent.
Mineral matter	36.3
Difference	7.9
	100.0
Bitumen soluble in 88° naphtha	38.0 per cent.
This is per cent. of total bitumen	66.2
Bitumen yields on ignition:	
Residual coke, ash free	12.7

The refined asphalt, although hard and rather brittle when struck a sharp blow, possesses sufficient viscosity to flow slowly under pressure at low temperatures. To make it available as a binding material for pavements and road surfaces, it is necessary to bring it to the proper consistency by mixing it with a heavy petroleum oil or flux of a nature which will be described later. This combination is known as asphalt cement.

Bermudez Asphalt.—Crude Bermudez asphalt is refined in the same way as the crude Trinidad material, that is to say, it is heated until the water is driven off. The refined material is much softer than the refined *Trinidad asphalt.* It varies in degree depending on the

art of the lake deposit from which the crude asphalt is ıken. Some of the characteristics of the supply which as been marketed in 1912, are as follows:

PHYSICAL PROPERTIES

Specific gravity at 77° F.	1.075
Melting-point	183° F.
Color of powder or streak	Black.
Luster	Bright.

CHEMICAL CHARACTERISTICS

Loss at 325° F. for five hours	2.8 per cent.
Character of residue	Smooth.
Bitumen soluble in CS_2	92.5 per cent.
Mineral matter	4.9
Difference	2.6
	100.0
Bitumen soluble in 88° naphtha	64.0 per cent.
This is per cent. of total bitumen	69.2
Bitumen yields on ignition:	
Residual coke, ash free	13.4 per cent.

As the asphalt is softer than that from Trinidad the mount of flux with which it must be combined, although certain amount is always necessary, is less than is nployed with the harder asphalt, as will appear later. : also hardens more rapidly than a Trinidad asphalt ement on being maintained in a melted condition, pecially with agitation, for an extended period of time ıd requires more careful watching on this account in rder that it may eventually have a proper consistency ; it exists in the finished pavement.

CHAPTER VIII

FLUXES

For the production of an asphalt cement of suitable consistency for use in sheet asphalt pavements or as a road binder, the refined native asphalt must be combined with heavy oils, or residues from the distillation of various petroleums, which are known as fluxes. These fluxes are as varied in character as the petroleums from which they are derived, and they vary from year to year as the available supplies of petroleum for their production vary.

For many years the fluxes or residuums originated in the paraffine petroleums of the East, but this source of supply is unavailable at the present time. Of the fluxes which are on the market in 1913 none of them originate in a straight paraffine petroleum. They are derived from semi-asphaltic and asphaltic oils which have the characteristics given in the following table. Many of them are available only in a limited amount commercially.

The fluxes in the table differ essentially as regards specific gravity, the amount of paraffine scale which they contain, the residual coke which they yield on ignition, and in the percentage of bitumen which is insoluble in 88° naphtha. The more asphaltic the flux the more residual coke it yields and the more material insoluble in naphtha it contains.

On account of these great variations, it is most important that any one preparing an asphalt cement should be thoroughly informed in regard to the character of the flux

FLUXES AVAILABLE IN 1913

Test No.	127,197	42,550-M	123,056	124,166	127,195	127,382	34,531-M	37,996-M	125,484
Identification	S. O. Co., Neodesha, Kan.	K. Co., S. O. Co., Brooklyn, N. Y.	S. O. Co., Baton Rouge, La. Refy.	S. O. Co., Whiting, Ind.	S. O. Co., Sugar Creek, Mo.	Indian Ref. Co.	Trinidad flux	Mexican flux	Cal. flux
Sp. gr. at 60° F.	.944	.933	.934	.931	.957	.981	1.007	1.003	1.024
Beaume equivalent	18.3	20.1	19.9	20.4	16.3	12.7	....	....	....
Flash ° F.	485	410	505	430	505	495	350	375	....
Paraffine scale	3.8%	4.4%	1.4%	3.3%	4.2%	3.1%	.3%	1.3%	.6
Residual coke, ash free	3.0%	3.5%	2.7%	2.0%	5.9%	7.7%	7.0%	10.0%	9.4
Sulphur	.6%	.4%	.6%	.5%	.7%	.5%	2.6%	4.3%	1.17
Loss seven hours 325° F., 20 grm.	.4%	2.0%	.1%	1.0%	.2%	.2%	6.0%	4.1%	.2
Insoluble in 88° naphtha, pitch	2.8%	2.5%	.4%	2.4%	8.5%	9.6%	13.9%	18.8%	12.5

which is at hand before attempting to use it. In the case of a flux of lower gravity a smaller amount is required to produce an asphalt cement of suitable consistency for paving purposes than of a heavier one. About 20 lb. of the lighter flux are required for each 100 lb. of refined Trinidad asphalt, and about 7 lb. with the present supply of Bermudez refined asphalt. A much larger amount of the heavy asphaltic fluxes is necessary owing to their greater density and viscosity. This may reach as much as 40 or 50 lb. per 100 of asphalt instead of 20, as in the case of the paraffine fluxes.

It must be remembered, however, that the character of the supply of fluxes which are available on the market is very variable from year to year, owing to the fact that the crude petroleum which is available for their production is obtained from different fields at different times, and that a supply which may be entirely satisfactory at one time may not be available at another. As an example may be cited the fact that ten years ago one of the best fluxes ever used in the paving industry was made from Beaumont petroleum. The product of this field, however, was soon exhausted, and recourse was necessary to other fields for the crude material for manufacturing flux. For this reason no definite advice can be given in a printed publication as to how the flux supply can be handled at any time in the future. This must be carefully studied on an experimental scale in the laboratory before attempting to employ a new source of supply in practice.

In view of the facts which have been presented, it is evident that a specification which may provide for a satisfactory flux at any given time, will not serve that purpose in some subsequent year. In the present

status of the petroleum industry in the United States it is evident that there is no source of constant supply of flux and that the matter must be taken up anew every year.

CHAPTER IX

ASPHALT CEMENT

In the preparation of an asphalt cement the refined material and flux must be thoroughly combined to produce a satisfactory material. The refined asphalt must be carefully weighed, melted and raised to a temperature of at least 325° F. and not above 350° F. The flux should preferably be heated with steam coils, or otherwise, to a temperature of 150° to 200° F. for if it is run while cold into the melted asphalt, the two will mix slowly, and, unless much time is given the mixing may not be thorough. While the oil is being run in, agitation should be provided by means of a current of air or steam admitted, preferably through pipes at the bottom of the melting tanks. Steam is better, because air has a tendency to harden and also change the properties of the cement, in the same manner that occurs when blown products are prepared. The flux is usually supplied in tank cars. It is well to observe that there is no water in the tank cars before the oil is drawn into the supply tank, as it will cause foaming and much delay in making the cement. For the same reason if steam is used for warming the oil in the tank car, care should be taken that no water is introduced in that way through loose connections or leaky coils.

The agitation should be kept up for some hours until the asphalt cement is homogeneous and during the entire time that it is in use, in the case of Trinidad

asphalt to keep the mineral matter which it contains suspended in a uniform manner, and in the case of Bermudez to prevent overheating of the material where it is in contact with the hot sides of melting tanks, especially over fire, where they are not heated by steam coils. Under the most favorable circumstances three hours agitation is necessary and, with inferior agitation, a much longer time may be required. The character of the cement can be determined by pouring some of it into a pail of cold water and examining it on cooling. If any free oil is apparent more agitation is necessary.

When the asphalt cement is homogeneous, the next step is to determine whether the consistency is that which is desired. The ordinary method is by the use of the penetrometer, an instrument carrying a No. 2 cambric needle weighted with 100 grm. which is brought into contact with the surface of some of the asphalt cement in a tin box which has been brought to the standard temperature of 77° F. by being immersed in water for a considerable period of time. The needle is released and allowed to act five seconds. The distance to which it penetrates is read off by the movement of an indicator upon a circular scale upon a dial, each division of which represents a hundredth of a centimeter, and is generally referred to as a point. A cement may, therefore, be said to penetrate 40, 50 or 60 points. The consistency is varied somewhat, but very slightly, according to the conditions to be met. Ordinarily a penetration of 50 or 55 should be used with a well-graded sand aggregate containing plenty of filler. With a coarser and inferior one a harder cement must be employed. Testing the cement for consistency should be undertaken daily if the lot which *is being used* is not exhausted. Asphalt cement will

harden up a number of points if maintained in a melted condition overnight or for some time during bad weather. The extent will depend upon the method by which it is heated, whether over an open fire or by means of steam coils, and also upon the degree of agitation to which it is subjected. Too powerful an agitation is injurious. To correct the effect of agitation a certain amount of flux must be added daily, according to the judgment of the operator or plant foreman, to maintain the asphalt cement at the proper consistency.

The consistency of the cement can also be checked by noting the length to which a small cylinder of it made in a mould designed for the purpose, will flow on a corrugated brass plate in comparison with a cylinder of standard material when exposed in a closed box heated to the flowing point of the cement with a steam coil.

The consistency has been regulated at times very satisfactorily in the past by experienced plant foremen, by chewing the cement. This is more available in the case of Trinidad asphalt than Bermudez, but can be used with the latter by an expert. With other asphalts it is not reliable.

All that has been said in regard to asphalt cements for sheet asphalt surfaces applies equally well to those which are used in asphaltic concrete and for bituminous broken-stone roads, except that the consistency is necessarily somewhat softer for concrete and too soft for the convenient use of the penetrometer in the case of road binders. For an asphaltic concrete a penetration of about 90 is desirable, and 150 for broken-stone work, whether conducted by the penetration or mixing process. The softer cements are possible in these cases because of *the greater stability* of the mineral aggregate of the

concrete and of the stone in a broken-stone surface, and are used because the softer the cement is the more satisfactory the surface will be at low temperatures. The degree of softness is only limited by its susceptibility to the high temperatures to which it is subjected under a summer's sun. The native lake asphalts permit of the use of a much softer binding material in both cases than of the industrial products, which are most susceptible to the heat of the sun, and are drawn to the surface by it with unsatisfactory results, the surfaces "bleeding" as it is called.

CHAPTER X

SURFACE MIXTURES

Having considered individually the components which make up the various forms of asphalt surface mixture, their combination in a rational way and the reasons for so doing may be taken up.

Sheet Asphalt Mixture.—A sheet asphalt surface mixture consists of three essential components, a well-graded sand, sufficient filler and an asphalt cement of proper consistency. In the early days of the industry the surfaces which were constructed were of types which, while they withstood very satisfactorily the moderate travel to which they were subjected in such cities as Washington and Buffalo, were not suited to the more intense conditions to which such pavements are exposed to-day in the larger cities and, frequently, such surfaces were not satisfactory even under the less trying conditions. The variation in the composition of sheet asphalt surfaces laid in various cities before 1894 was large and is shown in the following table, taken from the writer's book "The Modern Asphalt Pavement."

There is no uniformity in the grading of the mineral aggregates of these mixtures, and in many cases there is a deficiency of bitumen, the percentage varying from

SHEET ASPHALT SURFACE MIXTURES, LAID BEFORE 1894

City	Bitumen	Mineral aggregate passing mesh				
		200	100 & 80	50 & 40	30, 20, & 10	Total
Washington......	10.29	9.72	6.45	42.06	31.48	100%
Louisville........	8.91	14.50	9.06	38.30	29.23	100%
Newark..........	8.81	8.38	9.48	41.26	32.07	100%
St. Louis.........	9.61	10.87	12.12	60.10	7.30	100%
Youngstown.....	9.06	10.93	12.77	49.06	18.18	100%
New Orleans.....	9.87	11.27	15.34	52.59	10.93	100%
New York.......	10.97	12.13	16.39	34.14	26.37	100%
Scranton.........	10.64	12.15	22.01	37.58	17.62	100%
Boston..........	11.75	14.46	35.32	26.19	12.28	100%
Kansas City.....	9.85	13.10	25.92	31.31	19.82	100%
Schenectady.....	10.32	11.91	29.19	39.38	9.20	100%
Buffalo..........	9.65	11.32	30.53	44.68	3.82	100%
Chicago.........	9.24	9.33	35.95	38.83	6.65	100%
Omaha..........	9.44	12.80	41.98	24.93	10.85	100%
Average.........	9.89	11.63	21.61	40.03	16.84	100%
For comparison:						
Standard mixture	10.5	13.0	26.0	34.5	16.0	100%

8.8 to 11.7, not from a desire to reduce the amount but because the mineral aggregate would, probably, not carry more. The mineral aggregate has evidently originated in each case in a local sand without regard to its character or suitability for the purpose for which it is used. As compared with what is now considered a standard grading the finer sand, 100 and 80 mesh, is

deficient in many cases, and is too great in amount in others. The percentage of coarse particles, which gives the surface stability and roughness, if present in the proper amount, but which renders it open and porous if present in too large a quantity, was, in several cases, not well regulated. The Washington, Louisville, Newark and New York mixtures contained too large a proportion of coarse, and the Boston, Omaha and Chicago mixtures too much fine sand. The great variations show how little attention was paid in the early days of the industry to the matter of selection of sand. The percentage of filler in the mixtures appears to have been in many cases sufficient, but this percentage is generally due to fine 200-mesh sand and not to the presence of an added filler, as in those days only about 4 per cent. was used. Some of the mixtures, therefore, would not carry enough bitumen. Others were unstable if they contained an amount considered suitable to-day, and some cracked or disintegrated when the bitumen was low.

After it had become apparent to the writer, as long ago as 1894, from a study of the surfaces which had been laid previous to that time, that the mineral aggregate must be more carefully regulated if uniform success was to be attained, an attempt was made to do so. Mixtures were turned out in 1897 which showed greater uniformity, as appears in the following table, taken from the same source as the preceding one, although the grading was not ideal in every respect owing to local limitations. Notwithstanding the latter fact, all of these mixtures, with the improved grading of the aggregate and more filler, carried over 10 per cent. of bitumen. They average 10.5.

The results show the possibility, with care, of bringing

AVERAGE COMPOSITION, SURFACE MIXTURES, 1897

City	Bitumen	Passing mesh								Average penetration of A. C.
		200	100	80	50	40	30	20	10	
St. Louis, Mo.	10.5	20.8	11.4	16.3	28.7	6.0	3.4	1.8	1.1	63°
Kansas City, Mo.	10.4	18.9	13.1	13.7	30.9	4.6	3.4	2.6	2.5	61°
Elmira, N. Y.	10.9	8.9	23.0	25.6	27.8	2.4	1.0	0.3	0.1	75°
Chicago, Ill	10.8	14.0	16.4	16.5	32.4	4.5	2.4	1.5	1.5	56°
New York, N. Y.	10.7	16.4	12.9	12.4	24.7	8.4	7.1	4.1	3.2	58°
Buffalo, N. Y., 4-B Plt.	10.1	14.0	15.2	14.4	38.7	4.9	1.9	0.6	0.3	61°
Buffalo, N. Y., 3-B Plt.	10.6	14.8	14.2	11.1	38.2	7.1	2.5	0.8	0.7	67°
Niagara Falls, N. Y.	10.2	14.5	13.9	13.2	37.5	6.9	2.9	0.6	0.2	63°
Boston, Mass.	10.1	14.8	13.4	11.2	23.9	9.1	7.6	4.7	5.2	59°
New York, N. Y., Bronx.	10.1	14.2	12.5	9.2	24.6	10.8	10.2	5.6	2.8	62°
Yonkers, N. Y.[1]	10.5	14.6	12.1	10.7	25.3	9.7	7.5	4.3	4.7	58°
Newark, N. J.	10.2	15.5	10.9	8.8	24.5	9.4	9.8	6.5	4.3	58°
Jersey City, N. J.	11.4	14.6	11.4	13.9	26.7	8.8	6.3	4.0	2.9	55°
Sioux City, Iowa.	10.5	16.0	9.7	9.8	28.7	9.2	8.1	4.2	3.7	61°

[1] Retained on 10 mesh, .5 per cent.

AVERAGE COMPOSITION, SURFACE MIXTURES, 1897.—*Continued*

City	Bitumen	Passing mesh								Average penetration of A. C.
		200	100	80	50	40	30	20	10	
Saginaw, Mich.	10.0	13.1	12.1	7.8	29.7	15.6	8.7	2.1	1.0	56°
Buffalo, N. Y., 1-B Plt.	10.4	13.7	11.5	14.6	41.5	5.1	2.1	0.7	0.4	61°
New Orleans, R. R., Plt.	10.6	14.5	9.9	10.8	21.7	11.2	10.2	6.5	4.6	51°
Detroit, Mich.	10.8	12.4	11.3	13.7	41.2	4.3	2.4	1.7	2.2	57°
Pittston, Pa.	10.6	11.3	11.9	12.8	32.8	7.6	7.1	3.2	2.6	51°
New Orleans, La.	10.1	12.7	10.0	8.9	25.9	11.9	10.4	5.9	4.1	45°
Wilkesbarre, Pa.	10.5	12.8	8.2	8.5	26.6	13.7	9.7	6.3	3.7	51°
Rockford, Ill.	10.1	13.2	7.6	7.3	30.5	15.6	12.2	2.7	0.8	54°
Scranton, Pa.	10.4	12.3	8.1	10.3	27.9	11.0	10.6	5.3	4.1	57°
Harrisburg, Pa.	10.3	13.1	6.9	5.0	34.1	19.9	6.8	2.8	1.1	63°
Washington, D. C.	10.8	10.2	7.5	6.7	24.2	15.4	12.0	8.5	4.8	60°
Akron, Ohio	11.1	10.9	6.4	12.7	41.0	8.6	5.9	1.9	1.4	57°
Average	10.5	.....	.....	.....	.....	.....	.....	.....	.....	58°

about some uniformity in the production of asphalt surface mixtures.

The penetrations as given in the last column of the table are in units of the old Bowen penetration machine which are, approximately, 20 points higher than the readings of the present instrument. The average penetration of the cement would be, therefore, only 38 as now determined. This would, to-day, be regarded as much too hard since experience has shown us that, with a better-graded mineral aggregate a softer cement can be used, one 20 points softer than in the year under consideration. The readings given in the table may, therefore, be regarded as suitable penetrations, to-day, with the instrument now in use, for new work.

Probably the improvement which has been made in sheet asphalt surfaces in recent years is to be attributed to the fact, as far as the higher percentage of bitumen which they contain is concerned, that a well-graded mineral aggregate will carry a larger percentage. Too small an amount reduces the strength of the material, especially at low winter temperatures, and in addition, makes it more susceptible to water action.

As illustrating the points to be given careful consideration in the preparation of a satisfactory surface mixture some of the writer's experiences and the results of his studies may be cited.

In 1894 an attempt was made to construct a Trinidad sheet asphalt pavement on the Kings Road in Fulham, London, England, on the lines which had been followed previous to that time in America. The results were not successful as the mixture scaled under heavy travel in the damp climate at that point. It analyzed as follows:

KINGS ROAD, FULHAM, LONDON, 1894

Bitumen	10.0
Passing 200 mesh	7.4
Passing 100 mesh	15.9
Passing 80 mesh	11.4
Passing 50 mesh	11.1
Passing 40 mesh	24.0
Passing 30 mesh	12.2
Passing 20 mesh	5.0
Passing 10 mesh	3.0
	100.0

After a study of the conditions existing there, and the necessity of carefully regulating the mineral aggregate, a satisfactory mixture was turned out in 1896, which had the following composition:

KINGS ROAD, FULHAM, LONDON, 1896

Bitumen	10.8
Passing 200 mesh	13.6
Passing 100 mesh	7.3
Passing 80 mesh	22.5
Passing 50 mesh	25.5
Passing 40 mesh	8.9
Passing 30 mesh	6.6
Passing 20 mesh	3.0
Passing 10 mesh	1.8
	100.0

A comparison of the two mixtures reveals at once why one was satisfactory and the other not. While the sand *in both cases had* an acceptable grading, the mixture in

1894 was deficient in filler, carrying only about one-half as much as that of 1896. In consequence of the lack of filler the 1894 mixture carried nearly 1 per cent. less bitumen. Further studies of the London conditions have led to the production of a mixture at that point which now carries as much as 17 per cent. of filler and 11.5 per cent. of bitumen, which is, correspondingly, more satisfactory. Reference to this mixture will be made later. The 1896 surface constructed with the mixture, the composition of which has been given, resisted fairly satisfactorily the trying climatic conditions and the heavy travel to which it was subjected in London, but required considerable maintenance. This was, no doubt, due to a smaller percentage of filler and bitumen than in subsequent mixtures and, probably, also to the fact that it was placed upon and only supported by an ordinary open binder which was inadequate. In 1906 under the author's supervision, the more satisfactory mixture which was referred to, was laid upon an asphaltic concrete close binder, on the Thames embankment, and has proved to be an extremely satisfactory piece of work. It was made with materials in the following proportions, and had the composition given below:

THAMES EMBANKMENT, 1906

Asphalt cement (lb.)	152
Dust (Portland cement) (lb.)	170
Sand	600
Per cent. A. C	16.5
Per cent. dust	18.4
Per cent. sand	65.1
	100.0

ANALYSIS

Bitumen	11.5
Passing 200 mesh	17.5
Passing 100 mesh	7.0
Passing 80 mesh	23.0
Passing 50 mesh	32.0
Passing 40 mesh	6.0
Passing 30 mesh	3.0
Passing 20 mesh	0.0
Passing 10 mesh	0.0
	100.0

Attention has been called to the high percentages of bitumen and filler, the former being possible because of the presence of the latter and the large amount of filler being possible only because of the very fine sand. The mixture, it will be seen, may be considered as being deficient in coarse material and would, no doubt, be improved in certain directions if more coarse sand were present, but in this case it would not carry as high a percentage of bitumen and on this account might not prove as satisfactory in a moist climate like that of London.

After the work in London in 1896, the Fifth Avenue pavement in New York between 9th and 59th Street was laid by the writer in 1896–97. The average composition of the mixtures laid in these two years is given in the following table for comparison with that of the *London mixture:*

FIFTH AVENUE, NEW YORK CITY

Passing mesh

	Bitumen	200	100	80	50	40	30	20	10
1896.........	10.8	15.4	10.5	10.7	22.3	10.9	8.9	4.9	5.6
1897.........	10.6	17.4	12.3	11.1	23.3	8.8	8.0	4.7	3.7
For comparison									
London, 1896	10.8	13.6	7.3	22.5	25.5	8.9	6.6	3.0	1.8
London, 1906	11.5	17.5	7.0	23.0	32.0	6.0	3.0	0.0	0.0

Comment on the sands composing these mixtures has been made in the chapter relating to mineral aggregates, but the data in regard to the completed mixtures show their desirable features. They carry a proper percentage of bitumen, over 10.5 per cent., a fair percentage of filler, a satisfactory amount of sand of 100- and of 80-mesh size, and a considerable percentage of coarse material, 10, 20 and 30 mesh. In the latter respect they are perhaps preferable to the Thames embankment mixture of 1906. and correspond more closely with the London mixture of 1896. The Fifth Avenue surface has proved most satisfactory under the conditions to which it has been exposed. A more detailed account of the mixture and these conditions are contained in an article published by the writer in the *Engineering Record* for January 4, 1913, to which the reader is referred.

How far the type of mixture laid on Fifth Avenue in New York in 1896–7 has been departed from in recent years, owing to the fact that the sand supplies available

in that city are no longer the same as in that year, and because of the fact that such a standard grading is not demanded by municipal officials, may be seen from data in regard to the composition of a typical mixture laid in the Borough of Manhattan in 1912:

Bitumen	10.6
Passing 200 mesh	13.4
Passing 100 mesh	8.0
Passing 80 mesh	8.0
Passing 50 mesh	26.0
Passing 40 mesh	11.0
Passing 30 mesh	15.0
Passing 20 mesh	5.0
Passing 10 mesh	3.0
	100.0

On comparison of the composition of this mixture with that of the Fifth Avenue mixture given on a preceding page, it appears that it is deficient in fine sand of 100- and 80-mesh size, and carries 23 per cent. of 10-, 20-, and 30-mesh grains, as compared to 16.4 per cent. in the mixture laid on Fifth Avenue in 1897. It is a coarser mixture. It complies with the specifications of the highway department of the borough, which are drawn to meet the possibilities as far as the sand supplies are concerned which now exist in New York. A more satisfactory sand would have to be brought from a long distance, and would increase the cost of the pavement to some extent, something which the engineers do not consider justifiable. In the most recent specification, that for 1913, the requirements for the mineral aggregate in the Borough of Manhattan, *are as follows:*

Mineral aggregate	Percentage of total mixture as laid	
	Medium traffic mixture	Heavy traffic mixture
ained by 10-mesh sieve......	None	None
sing 10-mesh sieve, retained y 40-mesh sieve.	10 to 35%	10 to 30%
sing 40-mesh sieve, retained y 80-mesh sieve.	20 to 55%	20 to 55%
sing 80-mesh sieve, retained y 200-mesh sieve.	10 to 30%	13 to 30%
sing 200-mesh sieve..........	12 to 18%	13 to 20%
imen......................	9.5 to 12.5%	10 to 12.5%
etration of asphaltic cement..	45 to 65	40 to 55
er........................	Stone dust or Portland cement.	Stone dust or Portland cement.

n 1900 a sheet asphalt surface was laid in Paris, nce, which was still in satisfactory condition in 1912, l was of the character shown by the following data:

AVENUE VICTORIA, PARIS, 1900

Bitumen........................	10.9
Passing 200 mesh................	15.8
Passing 100 mesh................	14.6
Passing 80 mesh................	18.8
Passing 50 mesh................	28.2
Passing 40 mesh................	5.8
Passing 30 mesh................	3.4
Passing 20 mesh................	1.5
Passing 10 mesh................	1.0
	100.0

The mineral aggregate was composed of the mixture of three sands which sifted as follows:

PASSING MESH

	200	100	80	50	40	30	20	10
No. 1	10.0	78.0	7.0	4.0	1.0	....	....	....
No. 2	1.0	7.0	43.0	48.0	1.0	....	....	....
No. 3	2.0	6.0	13.0	28.0	26.0	12.0	10.0	3.0

The above sands were combined in the proportions of 1 part No. 1, 3 parts No. 2 and 4 parts No. 3. Portland cement was used as a filler. The mixture was made in the following proportions:

Sand	700 lb.
Portland cement	140 lb.
Asphalt cement (Bermudez)	112 lb.

The preceding mixture is typical of one constructed to meet the trying conditions encountered in Paris, that is to say, winters when pavements are not dry during the entire season, and at that time, 1900, heavy horse-drawn omnibus travel.

The surface mixtures laid in London, Paris and on Fifth Avenue, New York, have been cited as concrete examples of types which will withstand heavy travel. The pavement on the Thames embankment is, without doubt, the one which has met the most trying conditions in the most satisfactory manner. The reason that it has done so is plainly due to the fact that it has a rigid

foundation, its mineral aggregate is fine, it carries a very large percentage of filler, 17.5, consisting of Portland cement, and in consequence a very high percentage of bitumen, 11.5, a possibility due to the fineness of the aggregate. It is, of course, an expensive mixture and one that would not be used unless difficult conditions were to be met, but it points to the necessity of high percentages of filler and bitumen in sheet asphalt surface mixtures to make them resistant to dampness and heavy travel.

In "The Modern Asphalt Pavement," published by the writer some years ago, the following attempt at explaining the points to be observed in constructing a surface mixture in a rational way, made in 1896 in a small pamphlet prepared for the use of plant foremen and superintendents, was reprinted. It is still useful for the purpose for which it was originally intended.

"With the object of explaining to the practical man, the superintendent or yard foreman, the features of such a standard mixture it was considered from the point of view of consisting of a mineral aggregate composed of sand and dust and a proper percentage of bitumen. The mineral aggregate must be regarded as being made up of three elements, the fine sand, which is the most important, the coarse sand, which is desirable, and the dust or filler, which is absolutely necessary. The mineral aggregate of a standard mixture may, therefore, be considered from the following points of view.

First point, 100- and 80-mesh sand.......	17+17=34 per cent.
Second point, 10-, 20-, and 30-mesh sand	10+8+5=23
Third point, Filler+200 sand. Dust+fine sand	=17

Or for the complete surface mixtures:

First point, 100- and 80-mesh sand....... 13+13=26 per cent.
Second point, 10-, 20-, and 30-mesh sand 3+5+8=16
Third point, filler+200 sand.................. =13
Fourth point, bitumen........................ =10.5

Or these points may be expressed in one of the following ways:

ASPHALT SURFACE MIXTURE

Correct surface mixture, 100%
- Bitumen 10.5% (4th point)
- Mineral aggregate, 89.5% (1st point) (2d point) (3d point)
  - Filler, 13.0% (3d point)
  - Sand, 76.5% (1st point) (2d point)
    - Mesh.
    - 100 . 13.0 } 26.0%
    - 80 . 13.0 } 26.0% (1st point)
    - 50........23.5%
    - 40........11.0%
    - 30..8.0 } 16.0%
    - 20..5.0 } 16.0%
    - 10..3.0 } 16.0% (2d point)

ASPHALT SURFACE MIXTURE

Composition

Composition				
Bitumen........................10.5—4th point				Correct asphalt mixture, 100%
Filler+200 sand........13.0—3d point			Mineral aggregate, 89.5%	
100 sand, 13.0 80 sand, 13.0	26.0— 1st point	Sand 76.5%		
50............	23.5			
40............	11.0			
30........8.0 20........5.0 10........3.0	16.0— 2d point			

The surface mixture, therefore, may be regarded:

First, as a whole.

Second, as a mixture of bitumen and a mineral aggregate.

Third, as a mixture of bitumen, filler, and sand.

Fourth, as a mixture of bitumen, filler, 100- and 80-mesh sand and 10-, 20-, and 30-mesh sand in suitable proportions.

For example, take a New York mixture:

First, New York mixture.

Second, 10.5 per cent. bitumen, 89.5 per cent. mineral aggregate.

Third, 10.5 per cent. bitumen, 13.0 per cent. dust, 76.5 per cent. sand.

Fourth,

Bitumen.....	200 Dust	100	80	50	40	30	20	10
10.5	13.0	26.0		23.5	11.0	16.0		
or								
10.5	13.0	13.0	13.0	23.5	11.0	8.0	5.0	3.0

"In forming an opinion, therefore, of an old or new surface mixture it becomes evident that the four points which have been described must be considered. These points may be differentiated from the composition of an old mixture or combined to form a new one.

"The primary consideration is the sand and the first point that it shall contain a normal and sufficient amount of 100- and 80-mesh material. This was, and undoubtedly is to-day, the most essential feature in making a satisfactory mixture. It is essential because without this fine sand the mixture is porous and open, and more particularly because, unless it is present, a sufficient

amount of dust or filler cannot be used. The fine sand prevents the dust from balling up and making a lumpy mixture and, as will eventually appear, the larger the amount of fine sand the more dust can be introduced without difficulty. In the earlier mixtures, 1880 to 1896, a large percentage of dust could seldom be used, although the attempt was often made, as the resulting mixture was difficult to handle and rake.

"The second point or consideration lies also in the sand grading and is the regulation of the amount of the 10-, 20-, and 30-mesh sand grains. In the Fifth Avenue mixture this material amounted to 16 per cent. It was unavoidable there, owing to the character of the sand available, but was believed to be desirable in several ways. In the first place, it seemed to fill the place taken by broken stone in hydraulic concrete, and to carry the traffic, so to speak. In the second place, it gave a less slippery surface than a finer mineral aggregate. In both these ways the coarse material is desirable, but closer study and experience has shown that at times it may be reduced or largely omitted to advantage, especially in damp climates.

"To bring about a satisfactory arrangement of the first two points, or sand grading, one or more kinds of sand are necessary, usually more than one. For example, in the Fifth Avenue mixture the main sand supply was deficient in 100- and 80-mesh grains. It was, therefore, necessary to add a certain amount of fine sand consisting predominantly of grains of this size.

"The third point, and one also of great importance, is that the amount of filler or dust shall be sufficient. In the standard mixture of 1899 this was intended to reach, *together with the* small amount of 200-mesh sand and

the natural filler present in Trinidad asphalt, 13 per cent. In the older, coarse Washington and St. Louis mixtures of the early nineties the filler and 200 sand rarely reached 7 per cent., and in St. Louis fell, at times, below 3 per cent. This was attributable to two causes: one, the fact that such coarse mixtures would not carry much dust without balling, and the other, because it was considered at that time uncertain if there was any merit in using a filler. We now know that dust gives stability to the mixture, aids in excluding water, and that the best surfaces are those which, up to a certain limit, contain the most filler. In the standard mixture of 1899 the largest amount of dust which such a sand grading could carry was about 13 per cent., owing to the relatively small amount of 100 and 80 sand grains. Beyond this percentage the mixtures would become greasy or would ball.

"With the first three points arranged in a satisfactory way, the fourth or last point was to decide on how much asphalt cement the mineral aggregate would carry. This has been determined in recent years by the pat test which readily shows whether an excess or deficiency in asphalt cement has been used. This test cannot, in all probability, be improved upon. If each grain of material in the mineral aggregate is coated with asphalt cement and the voids more than filled the excess will be squeezed out in making a pat and stain the paper excessively. If the voids are not filled the only stain upon the paper will be a light one from the cement coating the grains of sand. A perfect mixture will contain just enough cement to fill the voids in the aggregate, stain the paper well but not excessively. The hotter the mixture the more liquid *the asphalt* cement and the freer the stain. Cold

mixtures will give no indication, while the difference in the markings of a fine and coarse sand will be readily learned by experience.

"The preceding instructions are satisfactory for turning out a mixture for the conditions ordinarily met with if the available materials admit of following them, or for judging the character of old surfaces when they have been resolved into their constituents by analytical methods."

The pat paper test which is referred to above, is thus described in the author's book, "The Modern Asphalt Pavement."

"A small wooden paddle with a blade 3 to 4 in. wide, 5 or 6 in. long, and 1/2 in. thick, tapered to an edge at one end and with a convenient handle at the other, is used to take as much of the hot mixture from the wagon as it will hold, being careful to avoid any of the last droppings from the mixer which may not be entirely representative of the average mixture. Samples of mixture should never be taken from the mixer itself, but only from the wagon after mixing is completed.

"In the meantime a piece of brown Manila paper with a fairly smooth surface, 10 or 12 in. wide, and torn off at the same length from a roll of this paper, which can be had at any paper warehouse, is creased down the middle and opened out on some very firm and smooth surface of wood, not stone or metal, which would conduct heat too rapidly. The hot mixture is dropped into the paper sideways from the paddle and half of the paper doubled over on it. The mixture is then pressed down flat with a block of wood of convenient size until the surface is flat. It is then struck five or six sharp blows with the block until the pat is about 1/2 in. thick."

The paper will be found to be stained to a different

degree depending upon whether there is a deficiency, a proper amount or an excess, present. Examples of such stains are illustrated in the accompanying Figs. A to D.

In this way, the amount of asphalt cement in use in making a mixture, can be readily regulated, and the pat papers obtained will be evidence of the character of the mixture that is turned out. Where a laboratory examination is to be undertaken, a sample of surface mixture which is made from the material compressed between the paper can be used for this purpose, trimming it down into the proper form and sending it, accompanied by the paper, for the purpose.

Unfortunately at the present time the necessity for such control of asphalt surface mixtures as has been previously described has not been universally recognized. During the years 1911 and 1912 mixtures which were laid in various parts of the United States have come under the observation of the writer, some of which were far from satisfactory. As examples of poor work the following are illustrative:

Bitumen	200	100	80	50	40	30	20	10	On 10
8.6.......	9.4	11.0	18.0	31.0	5.0	9.0	4.0	3.0	1.0

Penetration, 68.

This mixture laid in a northern city in 1912, is made with a sand of very desirable grading, corresponding practically to the standard, but it is deficient in filler

and, in consequence, does not carry enough bitumen. Of the components entering into the mixture but 8.2 per cent. was dust, and it is probable that this was a coarse material, and at least half as much again should have been used. With a sufficient amount of filler the asphalt cement would be of suitable consistency for use in the cold climate where this pavement was laid, but with the absence of sufficient filler it would seem to be too soft.

In a small southern city, in the same year, a surface mixture was laid, of which the extremes and average composition as regards percentage of bitumen were as follows:

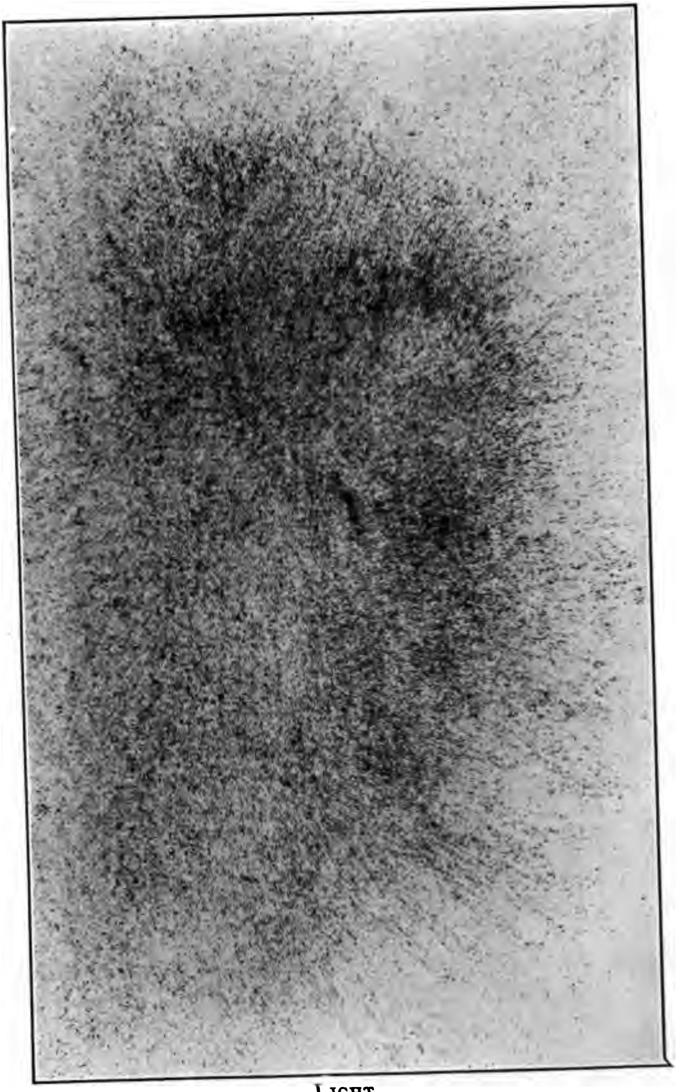
PASSING MESH

	Bitumen	200	100	80	50	40	30	20	10
High......	13.0	13.0	6.0	8.0	27.0	10.0	19.0	3.0	1.0
Low.......	9.9	11.1	4.0	5.0	23.0	12.0	23.0	7.0	5.0
Average...	11.4	12.6	6.0	6.0	22.0	11.0	21.0	5.0	4.0

Penetration

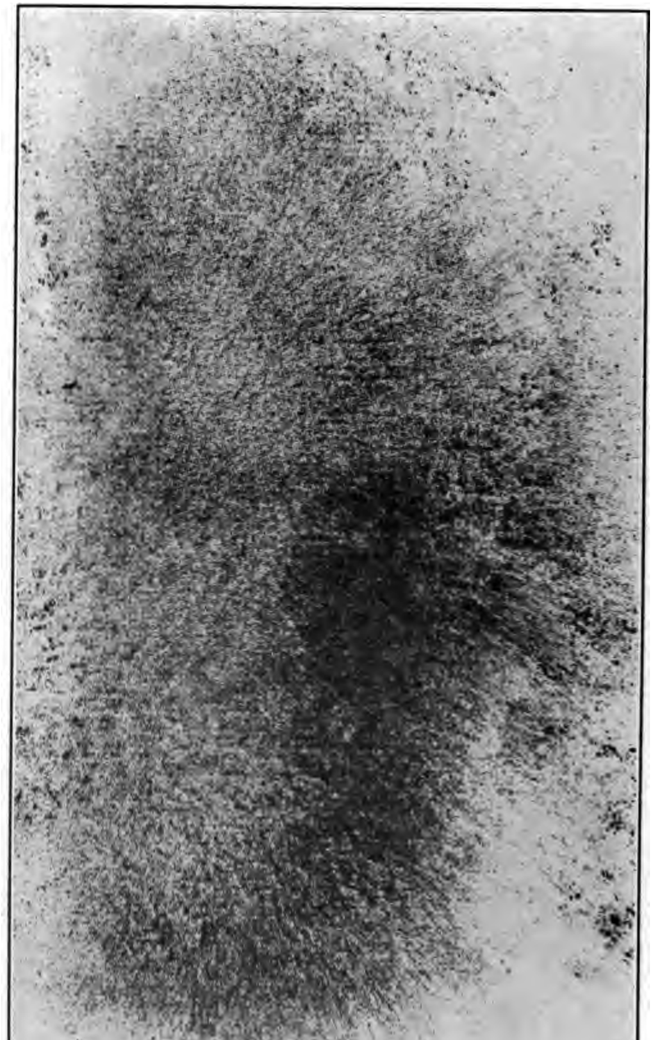
High	Low	Average
92	30	55

There is a great lack of uniformity in this mixture, both in percentage of bitumen and in its consistency, the variations being far greater than should occur in good practice. The amount of dust was only 60 lb. with 11 cu. ft. of sand, which shows that there must have been *a deficiency in* filler, although the amount of material

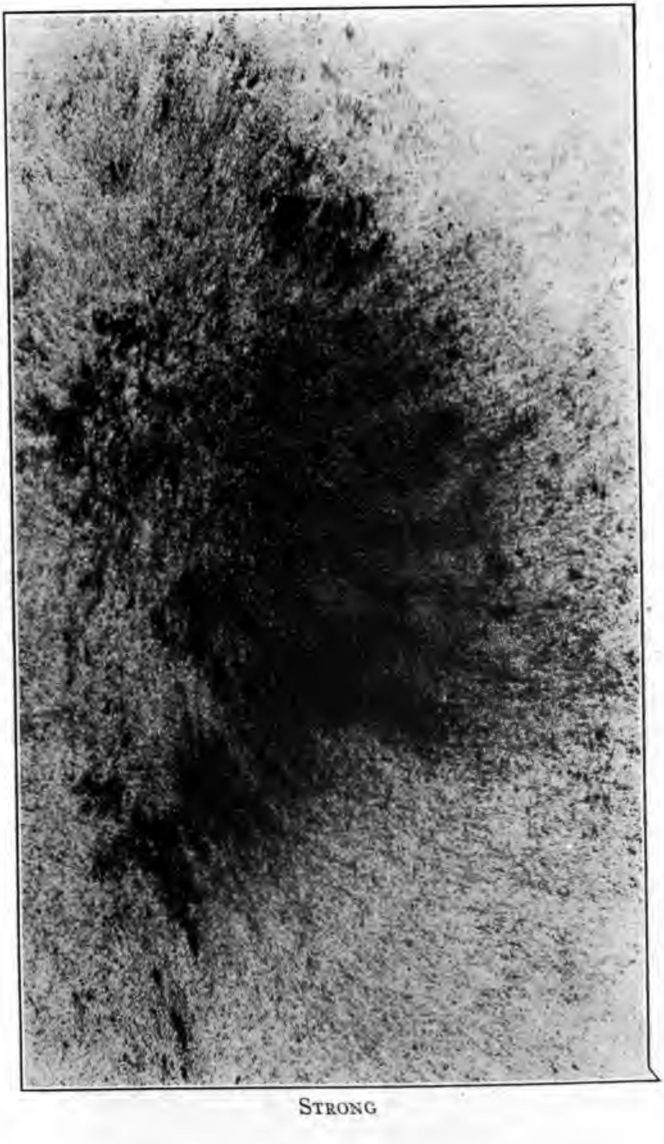


LIGHT

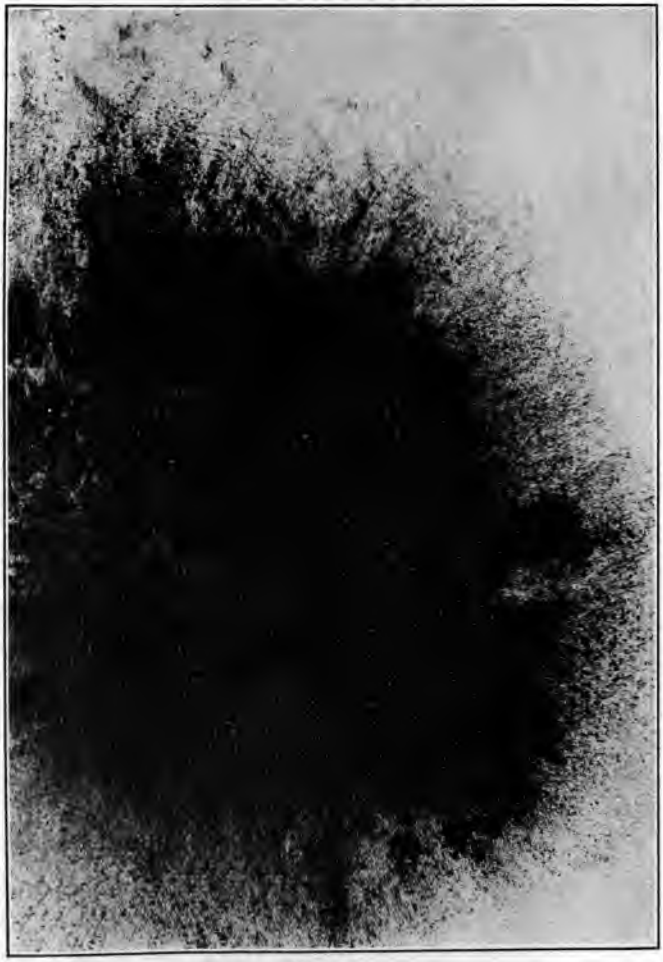
(Facing Page 7(



MEDIUM



STRONG



HEAVY

passing a 200-mesh sieve appears to be sufficient. The sand grading shows a lack of particles of sizes passing the 80- and 100-mesh sieves and a large amount of coarse sand, but in a small city this is not a serious consideration if the mixture is satisfactory in other respects.

In another northern city a mixture was laid which shows similar wide variations.

PASSING MESH

Bitumen	200	100	80	50	40	30	20	10	On 10
11.0......	10.0	12.0	12.0	33.0	9.0	10.0	2.0	1.0	....
8.2......	5.8	5.0	5.0	52.0	6.0	10.0	4.0	3.0	1.0

Penetration, 133–50.

It will be seen that the sand grading in this town was not carefully regulated. It was at times good, as in the case of the mixture carrying 11 per cent. of bitumen, and at times very bad, as in the case of the mixture carrying 8.2 per cent. of bitumen. The percentage of filler was very deficient at times, which, with the sand grading accounts in part for the low bitumen, and at other times approaches a more satisfactory figure. The penetration of the asphalt cement varied from 133 to 50, which is unsatisfactory.

In 1911 a sheet asphalt pavement was laid in an Ohio town, the surface mixture for which carried 9.2, 9.3 and 9.4 of bitumen in three cases, 11.2 in two cases and 11.00 *in another.* The amount of filler was usually deficient,

running as low as 6.6, 6.9 and 7.0, and averaging about 8 per cent. The following are data in regard to the extremes occurring in this town:

PASSING MESH

Bitumen	200	100	80	50	40	30	20	10	On 10
11.2......	11.8	6.0	14.0	31.0	10.0	10.0	3.0	2.0	1.0
9.2......	6.8	10.0	14.0	36.0	8.0	12.0	2.0	2.0	....

Here again we see that a deficiency of filler necessitates the use of a small amount of asphalt cement. The sand grading in this city was apparently satisfactory, and all that was needed to make a good mixture was the proper use of filler and asphalt cement.

In a southern city in 1911 a surface mixture was turned out having wide variation in its composition, as shown from the following data:

PASSING MESH

Bitumen	200	100	80	50	40	30	20	10
11.2..........	12.8	10.0	12.0	29.0	8.0	14.0	2.0	1.0
8.5..........	10.5	12.0	13.0	30.0	8.0	14.0	3.0	1.0

These mixtures are made with a most satisfactory sand. *The percentage* of filler seems to be satisfactory, as over

10 per cent. usually passes the 200-mesh screen but, on reference to the proportions used in the mixture, it appears that only 80 lb. of dust were used for a 9 cu. ft. box which, of course, with Bermudez asphalt, is too little, showing that much of the 200-mesh material must be sand and not serviceable as a filler. The percentage of bitumen shows wide variations, and is usually lower where the percentage of filler is low. The consistency of the asphalt cement is, in the opinion of the writer, too hard, varying from 28 to 40, even for a southern city, at least, if sufficient filler is used in the mixture.

The facts which have been given in regard to inferior mixtures show the necessity of more careful attention to the principles which have been laid down in the preceding pages, and point to the conclusion that greater carelessness exists to-day than should be the case. It cannot be considered, however, that much of the work which has been done within the last few years will prove to be an immediate failure, but it can be confidently asserted that mixtures of the type which have been laid in many instances in 1911 and 1912, will prove to be short-lived as compared to those constructed on rational principles and on lines which have given the best results under trying conditions, that is to say they will prove to be pavements which will last not fifteen years, but only ten or even five years, and it is with a view to correcting these mistakes that this book has been prepared, as well as to call attention again to the principles which were laid down at considerably greater length in the writer's original publication, "The Modern Asphalt Pavement."

Density of Sheet Asphalt Surfaces.—The density of a sheet *asphalt* surface is an important consideration in

determining its character, and its behavior in the laboratory, under impact when compressed is a valuable means of judging the quality of the binding material and the capacity of a pavement made with such a mixture to resist the impact of the horse's hoof and travel in general. A surface mixture when heated can be compressed in a steel cylinder in the laboratory under the impact of a hammer or falling weight, and it will be found that the density of the best mixtures, thus compacted, will be, where ordinary limestone is used as a filler from 2.22 to 2.25, and 2.27 when made with Portland cement. The calculated density of such mixtures is only about two units higher in the second place of decimals, than when laid on the street and thoroughly rolled, so that they contain practically no voids. In many inferior mixtures which have not given satisfaction, the density, as taken from the street surface, is found to be low, from 2.00 to 1.86. The character of a mixture can, therefore, not only be determined by observing its density in the laboratory but also from the density which it attains in the street under travel.

By means of an instrument designed by Mr. Logan Waller Page, Director of the Office of Public Roads, U. S. Department of Agriculture, the resistance to impact of cylinders of the form which has been described, may be determined and valuable data obtained for the differentiation of different types of mixtures. In making these tests the cylinders are 1.25 in. in diameter and 1 in. high and weigh about 50 grm. They are firmly held beneath a plunger resting on the surface of a spherical bearing having a radius of 0.4 in. A weight of 2 kg. is then allowed to drop from the distance of 1 cm. *This is increased* 1 cm. at each blow until the test piece

breaks. The number of blows it will withstand has been found to be dependent upon:

1. The sand grading.
2. The character of the sand.
3. The amount of filler present.
4. The character of the asphalt in use.
5. The consistency of the asphalt cementing material and the temperature at which the tests are made.
6. The density and degree of compaction of the test piece.
7. The percentage of bitumen in the mixture.

Some results of such tests are presented in the accompanying table taken from "The Modern Asphalt Pavement," and are instructive.

The tabulated data demonstrate that surface mixtures made with Trinidad asphalt are superior to any others if properly proportioned, and that the most desirable are those the mineral aggregate of which is fine, or contains a high percentage of bitumen and filler. In fact, the character of the mineral aggregate and the percentage of bitumen have an important influence on the behavior of the mixture under impact. Data obtained at different temperatures show that the mixtures in which Trinidad lake asphalt is the cementing material are more resistant to impact at extremes of temperature than where the binding material is some other form of asphalt.

Resistance to Action of Water.—The ability of a mixture designed on rational principles to resist the action of water has been noted. The denser the mixture and the larger the percentage of bitumen which it contains, the more resistant the surface will be to water action, and the more suitable such mixtures will be to meet unfavorable conditions of this description.

IMPACT TESTS OF SURFACE MIXTURES AT VARIOUS TEMPERATURES

Test No.	Location	Density	Number of blows producing crack	Temperature °F.	Bitumen	Passing mesh 200	100	80	50	40	30	20	10	On 10	A. C. Penetration, Bowen
70,354	Standard N. Y. Bermudez mixture.	2.25	11	40	11.2	17.8	12	10	27	12	5	3	2	0	70
70,354	Standard N. Y. Bermudez mixture.	2.24	19	78											
70,354	Standard N. Y. Bermudez mixture.	2.24	24	100											
69,645	Standard N. Y. Trinidad mixture.	2.24	15	40											
69,645	Standard N. Y. Trinidad mixture.	2.26	29	78	11.1	16.9	12	10	24	13	7	4	2	0	68
69,645	Standard N. Y. Trinidad mixture.	2.25	24	100											
75,857	California residual pitch.....	....	12	40											
75,857	California residual pitch....	....	16	78	11.0	15.0	12	7	26	16	5	5	3	0	80
75,857	California residual pitch....	....	14	100											
75,374	Brooklyn Cont. No. 2 (1904)	....	7	40											
75,374	Brooklyn Cont. No. 2 (1904)	....	9	78	10.0	8.2	5	2	14	11	13	12	13	11	
75,374	Brooklyn Cont. No. 2 (1904)	....	19	100											
30,828	Minneapolis, Minn.........	2.27	6	78	8.7	11.3	10	12	34	17	4	2	1		
14,996	New York (1904)..........	....	12	40											
14,996	New York (1904)..........	....	15	78	12.0	7.0	5	5	16	12	11	12	20		
14,996	New York (1904)..........	....	13	100											
30,035	Rochester, N. Y. (1885)....	2.23	7	78	8.3	13.7	15	10	20	13	9	6	5		28

IMPACT TESTS OF SURFACE MIXTURES AT 78° F.

Test No.	Location	Density	Number of blows producing crack	Penetration of plunger inches	Bitumen	Passing mesh 200	100	80	50	40	30	20	10	On 10	A. C. penetration, Bowen
73,341	Brooklyn, N. Y.	2.27	20	.088	10.0	10.0	6	5	19	14	11	14	11	....	60
73,394	Very coarse sand	2.23	21	.095	10.0	11.0	5	4	16	16	15	11	11	1	63
72,417	Chicago, Ill.	2.37	28	.117	10.9	11.1	17	18	33	6	1	1	2	....	52
73,273	Very fine sand	2.20	29	.147	10.9	11.1	16	17	33	6	2	1	2	1	58
73,124	Harrisburg, Pa.	2.20	28	.098	11.4	13.6	7	8	31	16	7	4	2	....	65
73,374	Deficient in fine sand	2.20	25	.088	10.9	14.1	7	7	28	16	10	5	2	....	66
73,323	Kansas City, Mo.	2.10	19	.060	8.9	21.1	12	14	17	3	2	4	14	4	
.....	Rock asphalt mix	2.09	18	.057											
73,371	Long Island City, N. Y.	2.29	29	.138	11.6	13.4	10	7	29	14	8	3	4	....	69
73,456	Deficient in fine sand	2.23	28	.113	11.3	13.7	8	8	30	14	8	4	3	....	68
73,315	New York City	2.18	31	.147	11.0	14.0	8	6	29	14	9	6	3	....	63
73,382	High bitumen; deficient in fine sand.	2.14	30	.113	11.6	13.4	9	6	27	14	10	6	3	....	67
71,547	Niagara Falls, N. Y.	2.36	25	.129	10.2	13.8	11	13	27	13	6	4			
73,396	High in 200 mesh	2.32	25	.129	10.4	15.6	12	12	27	9	7	3	3	1	60
73,187	Pittsburgh, Pa.	2.26	18	.056	10.2	14.8	10	10	33	10	4	4	3	1	80
73,442	Deficient in fine sand	2.22	19	.057	10.5	13.5	7	8	38	9	6	4	3	1	76
.....	Seattle, Wash.	2.24	18	.065	12.0	16.0	17	12	20	11	6	4	2	....	80
.....	High oil bitumen	2.21	14	.060											
72,358	Spokane, Wash.	2.23	17	.057	13.2	11.8	14	10	19	8	8	8	8	....	65
72,648	Very high oil bit.	2.23	18	.063	13.0	12.0	15	10	19	9	7	9	6	....	64

This is well illustrated by the amount of water absorbed at different periods by the old and coarse Washington mixtures of 1893 as compared to the improved type laid at the present time, as shown in the following table:

ABSORPTION OF WATER BY CYLINDERS OF ASPHALT SURFACE IN POUNDS PER SQUARE YARD

	Washington, 1893		Standard mixture, 1906	
	Trinidad	Bermudez	Trinidad	Bermudez
7 days......	0.314	0.063	0.080	0.094
14 days.....	0.434	0.194	0.093	0.093
28 days.....	0.502	0.306	0.107	0.104

All of the preceding facts point to the necessity of selecting asphalt of the highest quality, a careful regulation of the character of the sand, the amount of filler and the percentage of bitumen in use in the construction of a durable sheet asphalt surface.

An appreciation of the necessity for the precautions which have been insisted upon in this chapter is well realized by some contractors. As illustrating this a circular of instructions has been issued by the chemist of a corporation[1] who is engaged in the supervision of sheet asphalt work, who has followed the principles which the

[1] *American Asphaltum* & Rubber Co.

writer has laid down in previous publications, and which reads as follows:

"LABORATORY RULES AND INSTRUCTIONS FOR PLANT FOREMEN AND CHEMISTS"

"1. No sand shall be hauled on the job unless it has been previously O. K'd. by main laboratory.

"2. The chemist testing the sand or sands shall go to the pit or other source of supply and take representative samples, test them and make a report of test to main laboratory. A 1 lb. sample of each sand so tested shall be sent to laboratory.

"(*a*) Should it be necessary to use more than one grade of sand a report of the test of the proposed mixture, together with a 1 lb. sample of this mixture, shall be sent to main laboratory.

"(*b*) Chemists in making a preliminary report of suitable sand should state kind of sand (lake, river, or bank), available quantities, accessibility to railroad, or distance of haul to plant, price per cubic yard (f.o.b. source of supply or plant) and general appearance and character of sand, *i.e.*, whether it contains clay, loam or other impurities.

"(*c*) In selecting a suitable sand for paving work, chemist should look for a clean moderate sharp sand having a grading that comes within the limits given below. In case more than one sand must be used to get the desired grading, chemist must state in what proportions different sands must be mixed.

"(*d*) Chemist in selecting a suitable sand must select a sand that will not vary more than 5 per cent. from the following gradings, *i.e.*, 5 per cent. for the three combined gradings.

"(*e*) Should it happen that no suitable sand coming within above limits is found available, a special report on available sand should be sent to main laboratory."

STANDARD GRADINGS

Mesh	Heavy traffic, per cent.		Light traffic, per cent.	
Passing 200	0.0	34%	0.0	20%
Passing 100	17.0		10.0	
Passing 80	17.0		10.0	
Passing 50	30.0	43%	30.0	45%
Passing 40	13.0		15.0	
Passing 30	10.0	23%	15.0	35%
Passing 20	8.0		10.0	
Passing 10	5.0		10.0	

3. Oil

"Upon arrival of each car of fluxing oil, plant chemist or foreman shall send in a 1 pt. sample of same to main laboratory.

4. Samples

"On first day's run of top mixture a 1 lb. representative sample of drum sand, filler (limestone dust or Portland cement) asphaltic cement and refined asphalt shall be sent to main laboratory.

"(*a*) During first week of each month a set of samples similar to above shall be sent to main laboratory.

"(*b*) Should there be a noticeable change in any of the above materials during the month a sample of same with accompanying report should be sent to main laboratory.

"(*c*) Should it happen that job does not last for a month, two sets of above samples must be sent in, one set on first day's run of top and the second a few days before completion of work."

5. Pavement Samples

A sample 12×12 in. from each street of finished pavement, carefully cut and neatly packed and labeled with form No.... should be sent by freight to main laboratory.

"(*a*) Should any street contain over 10,000 sq. yd. a sample similar to above should be sent in for each 10,000 sq. yd.

"(*b*) If more than four pavement samples are to be sent in it will not be necessary to send in sample from any street having a yardage of less than 2,000 sq. yd.

"(*c*) Should there be any noticeable change in mix, or materials entering into mix, a pavement sample of each different mixture should be sent in.

6. Progress Maps

"A weekly progress map properly filled out must be sent to main laboratory each week."

7. Penetrations and Mixture

"Plant chemist or foreman must get penetration limits and proposed mix from main laboratory before starting work.

"(*a*) Plant chemist or foreman may make any small changes in mix which he thinks advisable, but any such changes must be immediately reported to main laboratory, giving full information and reasons for making change."

8. Daily Work

"Blank form No.....shall be carefully and completely filled out each day by plant chemist or foreman.

"(*a*) On first report of top mixture the weight of one cu. ft. of drum sand should be noted.

"(*b*) If binder and top are run the same day separate reports should be made."

9. Binder Work

"When running binder, a 2-oz. representative sample of *asphaltic* cement from each kettle should be taken and label

No.....filled out and sent with the sample to main laboratory."

10. Top Work

"When running top, the following samples should be taken and sent to the main laboratory:

" (*a*) One 2-oz. sample of A. C. from each tank used.

" (*b*) One representative pat sample from mixture at plant.

" (*c*) One small sample of mixture taken from street.

" (*d*) Proper labels for above samples should be made out and sent in with report No.....

"(*e*) Samples should be so numbered that proper labels can be put on the right samples upon their arrival at the main laboratory."

11. Drum Sand

"Plant chemist or foreman should test drum sand grading at least once each day and as many more times as is necessary to keep a uniform grading. A report of each day's sand grading shall be made out on blank No..... and sent to main laboratory."

12. Plant Chemists

"If there is a plant chemist on the job he is to have complete charge of mix but at all times must co-operate with the plant foreman."

13. Estimates

"After mix has been regulated plant chemist must estimate quantities of materials required to complete work and make written report of same to superintendent, sending copy of this report to main laboratory and copy to manager of construction."

14. Information

"A copy of any information regarding mixture given to *any city official must* be sent to main laboratory and such

information must not be given without first advising main laboratory that it has been requested."

GENERAL INFORMATION FOR PLANT CHEMISTS AND FOREMEN

"It is the policy of this company in its paving work to combine quality with quantity, in fact put quality above everything, and in recognition of this fact we respectfully ask that plant foremen and chemists co-operate in every possible way in putting out a most uniform and high-class mixture.

"It is at the paving plant that the pavement is made and it is here that the qualities of the asphalt and other materials and the reputation of the contractor is at stake, and it is only by the fullest co-operation and harmony between every one connected with the plant that the best results can be obtained.

"The following points should be noted and carried out as near as possible by plant foremen and chemists with the view of obtaining the best results.

"1. Top mixture should have at least fifteen seconds dry mix and from forty-five seconds to one minute wet mix.

"2. A. C. scales should be checked and rebalanced every hour, or more often if mixture does not look uniform. Scales should be cleaned every day.

"3. Sand scales should be checked every day and cleaned at least once every week.

"4. Tanks should be cleaned every week, or more often, if using Trinidad or Bermudez Asphalt and direct heat.

"5. In using "Pioneer" asphalt the temperature of the mix should be kept as near 300° F. as possible during the summer and about 325° F. during the spring and fall months.

"6. Temperature of asphaltic cement in kettles shall not exceed 340° F. unless special instructions are issued from main laboratory.

"7. Any material over 380° F. or below 240° F. should be rejected.

"8. Binder should go out at a temperature of about 275° F. and any over 340° F. should be rejected.

"9. Temperatures and limits on other asphalts will be given before starting work."

H. D. PULLAR,
Chemist.

The above circular shows the realization of the necessity of closely regulating plant work, and the suggestions which it contains can be followed with advantage by any contractor or his employees.

Grit Mixtures.—Something has been said of this type of mixture in discussing the mineral aggregate. In the form of asphalt blocks it has been extensively used but, owing to the fact that the asphalt cementing material in that case must be made undesirably hard in order to permit of the transportation of the blocks from the point of manufacture to another where they are laid without losing shape, it is not one that has proved satisfactory under heavy travel. When used in the monolithic form and hot, a grit mixture, the cement under these circumstances being of the consistency employed in ordinary sheet asphalt surfaces, is very satisfactory and has proved successful, especially in Buffalo and Rochester, N. Y., for many years. Constructed under the so-called Topeka specifications it will, in the opinion of the writer, prove a failure, as is evident from the following facts which have been stated in an article contributed to the *Engineering Record* of June 29, 1912.

"The bituminous mixture used in the manufacture of *asphalt block* would fall, in composition, practically

if not exactly, within the limits in percentage of bitumen and of the various sized particles of the mineral aggregate provided for in Judge Pollock's ruling. Naturally an asphalt block could not infringe the Warren patent, as it has been in use for many decades. The composition and grading of the mineral aggregate of the average asphalt block and of the finer material of which it consists, when calculated to 100 per cent., with the exclusion of the fine stone, is represented by the following figures:

	Block as made		Stone out	
Bitumen	7.0		10.9	
Passing 200 mesh	14.0		20.7	
Passing 80 mesh	8.0	15.0	12.4	23.2
Passing 40 mesh	7.0		10.8	
Passing 10 mesh	28.5		44.2	
On 10 mesh	35.5		....	
	100.00		100.00	

"Using the extremes of composition within the limits specified by Judge Pollock, mixtures of two types may be made, one low in bitumen and high in coarse material, and the other rich in bitumen and with a minimum amount of coarse material. These types of mixtures and the character of the fine material which they contain, *with the fine* stone excluded, are as follows:

Bitumen	7.0	10.3	11.0	12.9
Passing 200 mesh	5.0	7.3	11.0	12.9
Passing 80 mesh	18.0	26.5	30.0	35.3
Passing 40 mesh	38.0	55.9	33.0	38.9
Passing 10 mesh	22.0	.....	10.0	.....
On 10 mesh	10.0	.....	5.0	.....
	100.0	100.0	100.0	100.0

"The satisfactory nature of a mixture containing fine stone is no greater than that of the finer portion or mortar, when the latter is looked at as an ordinary sheet asphalt surface. The composition of the sheet asphalt mixture now in use in the Borough of Manhattan is as follows and, although it is not an ideal mixture, being deficient in fine sand, it will serve as a basis of comparison:

Bitumen	10.8	10.8
Passing 200 mesh	12.2	12.2
Passing 100 mesh	5.0	
Passing 80 mesh	8.0	
Passing 50 mesh	37.0	59.0
Passing 40 mesh	9.0	
Passing 30 mesh	13.0	
Passing 20 mesh	3.0	18.0
Passing 10 mesh	2.0	
	100.0	100.0

"It is very evident from the preceding data that the grading of the finer part of the Topeka mixture is very unsatisfactory, that is to say, it would make a poor sheet asphalt pavement, and for the same reason an unsatisfactory surface even after the addition of fine stone. The limits prescribed by Judge Pollock necessitate the use of a mineral aggregate containing less than

30 per cent. of fine sand which will pass a 40-mesh screen, and from 25 to 55 per cent. of concrete sand retained on a 40-mesh screen and passing one of 10 meshes to the inch. Both of these requirements necessitate the omission of an amount of fine sand particles which is well known to be desirable and necessary in a satisfactory asphalt surface mixture, and the use of much too large a percentage of concrete sand of 10, 20 and 30 mesh size, which are well known to cause scaling of an asphalt surface when in excess."

"A so-called Topeka mixture has recently been laid in the neighborhood of New York City which has the following composition, complying with the terms of the ruling:

	Specification limits	Topeka mixture laid	Calculated with stone out
Bitumen	7–11	8.00	9.6
Passing 200 mesh	5–11	6.25	7.5
Passing 40 mesh	18–30	22.75	27.2
Passing 10 mesh	25–55	46.50	55.7
Passing 4 mesh	8–22	12.75	....
Passing 2 mesh	–10	3.75	....

"The finer portion of the mixture, from which the stone of pea size has been removed, if calculated to 100 per cent. will be found to consist of over half concrete sand, and to be very deficient in fine sand. It is not a well *balanced mixture.*"

"A surface which would be infinitely superior to that provided by the Topeka ruling would be one which would consist of a standard sheet asphalt surface mixture to which 20 to 30 per cent. of fine stone, such as is used in the manufacture of asphalt blocks, and less than 10 per cent. of the small material which will pass a 2-mesh screen, has been added."

Such surface mixtures have been in use for a great many years, and below are given the proportions and analysis, with grading, of one used in the Borough of Manhattan, in the City of New York, in 1904, and in Buffalo, N. Y. in 1911, and before that for many years:

	New York	Buffalo
Grit	565 lb.	....
Sand	475 lb.	....
Dust	150 lb.	....
A. C.	130 lb.	....
	1320	
Bitumen	7.2%	9.9
Passing 200 mesh	12.8	8.1
Passing 100 mesh	6.0	7.0
Passing 80 mesh	5.0	20.0
Passing 50 mesh	11.0	26.0
Passing 40 mesh	6.0	2.0
Passing 30 mesh	5.0	1.0
Passing 20 mesh	5.0	1.0
Passing 10 mesh	6.0	3.0
Retained 10 mesh	36.0	22.0
	100.0	100.0

Of course in addition to the amount of asphalt cement required by that portion of the mineral aggregate representing the sheet asphalt mixture, enough must be used in addition to coat the surface of the stone which is present.

It appears that the density of a well-compressed sheet asphalt surface is 2.2, or slightly more than this. As the grit mixture carries a considerable percentage of stone and a smaller percentage of bitumen, its density will be considerably greater when compressed. In an asphalt block, the entire mineral aggregate of which consists of crushed trap-rock, a material of high specific gravity, the density is about 2.5. In a grit mixture, the finer portion of the aggregate of which consists of sand with a lower specific gravity than trap-rock, the density would be lower, but it should reach at least 2.35 when compressed.

Instead of the crushed rock, suitable gravel may be used, but the rounded form of the particles of gravel and their very smooth surface, do not make a mixture which is as satisfactory under heavy travel, as that in which crushed rock is used. The rounded particles of gravel are more easily torn out of the surface under travel than fragments of stone. It is, nevertheless, an extremely valuable form of surface where horse-drawn vehicles form but a small portion of the travel, and will, no doubt, meet with success under proper conditions.

Asphaltic Concrete Surfaces.—A concrete consists for the largest part of broken stone, either of uniform or graded sizes, the voids in which are filled with a mortar, a Portland cement mortar in the case of hydraulic concrete, and an *asphaltic* mortar in the case of asphaltic concrete.

Material of this type has been used in the construction of paving surfaces since the early seventies of the last century, although it was not done at that time on a rational basis. The Evans pavement laid in Washington, D. C., in 1873 had the following composition:

	Entire pavement		Mineral aggregate	
Bituminous matter soluble in CS_2(Tar)	3.0%			
Mineral matter passing 200-mesh screen.	3.2		3.4%	3.4
Mineral matter passing 10-mesh screen.	37.1	37.1	38.2	38.2
Mineral matter passing 8-mesh screen.	2.7		2.8	
Mineral matter passing 1/4-in. screen.	10.5	13.2	10.8	13.6
Mineral matter passing 1/2-in. screen.	14.3		14.7	
Mineral matter passing 3/4-in. screen.	14.7		15.2	
Mineral matter passing 1-in. screen...	14.5	43.5	14.9	44.8
	100.0		100.0	

The above data show that the Evans surface consisted of 58 per cent. of stone in size varying from 1/4-in. to 1-in. material, the voids in which were filled with a tar mortar. This is plainly a true concrete. Asphaltic concrete, as far as the writer is aware, was first produced in 1896, and laid as a sidewalk in Long Island City, N. Y. It had the following composition:

Test number	82,157	
Bitumen	7.3%	
Passing 200-mesh screen	8.2	8.2
Passing 10-mesh screen	24.2	
Passing 8-mesh screen	1.2	
Passing 1/4-in. screen	7.9	9.1
Passing 1/2-in. screen	30.9	
Passing 1-in. screen	20.3	
Retained 1-in. screen	.0	51.2
	100.0	
Voids in mineral aggregate	15.5%	

Later on a similar mixture was laid as a street surface in Muskegon, Michigan, which had the following composition:

Test number	81,117	
Bitumen	7.4%	
Passing 200-mesh screen	7.4	7.4
Passing 10-mesh screen	34.0	34.0
Passing 8-mesh screen	2.8	
Passing 1/4-in. screen	11.2	14.0
Passing 1/2-in. screen	18.0	
Passing 1-in. screen	19.2	37.2
Retained 1-in. screen	.0	
	100.0	
Voids in mineral aggregate	16.8%	

The mixtures cited give a very good insight into the character of the grading of the mineral aggregate and composition of such a mixture as it should be turned out to-day. It is unnecessary to enter here into a discussion of the infringement of certain patent rights by such *mixtures, as this* is not a subject for the engineer to pass

upon, and lies wholly with the courts and with the interpretation of the law. Such concrete surfaces are undoubtedly very satisfactory for light horse-drawn travel and for motor travel of any description, when a standard asphalt is used as a binding material.

In a previous chapter on Broken Stone, the character of the material suitable for use in asphaltic concrete has been discussed. It should be a trap-rock or hard limestone, but preferably the latter, as there is better adhesion of the asphaltic cement to the granular fracture of hard limestone than to the glassy surface of trap-rock.

The manner of assembling the mineral aggregate for the asphaltic concrete is discussed at length under the heading, Close Binder, in a previous chapter.

In regard to regulating the percentage of asphalt cement in use in asphaltic concrete, this, of course, cannot be done with the pat paper, as in the case of a sheet asphalt surface mixture composed of sand alone. It must be done by eye and with the use of good judgment. Whether the amount is correct, can be best determined by the appearance of the material in the truck, after the haul from the plant to the street. Where it is to be used as a surface to carry travel it should have settled into a compact mass, the top of which should show a slight excess of bitumen as a rich coating, whereas if it is intended for a binder course no excess of bitumen should appear and there should be some evidence of the coarser fragments of stone on the surface. An asphaltic concrete cannot be expected to have the bright and glossy appearance of clean stone coated with asphalt, as in the case of open binder, owing to the presence of sand.

In the preparation of asphaltic concrete the asphalt *cement in use should* be much softer than that employed

in the ordinary sheet asphalt surface mixture consisting of sand alone. It should not be harder than the consistency represented by 80 or 90 points on the penetration machine.

Asphaltic Broken Stone Surfaces or Asphalt Macadam.—Experience having demonstrated that the ordinary water-bound broken-stone road will not meet the demands of travel which consists largely of motor vehicles, it has been generally recognized that some form of bituminous material must be used as a cementing material with broken stone to produce a surface which will resist travel of this kind. The inference can be readily drawn that the native asphalts which have been used successfully in sheet asphalt pavements would prove to be the most desirable material for the purpose, and this has been found to be the case in comparison with other materials, such as coal tar and the residuals of petroleum. It is undoubtedly due to the greater stability of the native asphalts under the conditions which are to be met.

Bituminous broken-stone surfaces are constructed by either the so-called penetration or by the mixing process. The asphaltic cement is not however used in the same way in both, although the character of the material should be quite the same.

In the penetration process the stone is placed in the road in the manner that it would be if a water-bound broken-stone road was to be constructed, and the asphalt cement is applied to it in the amount decided upon, as uniformly as possible. This may be done after the stone is thoroughly compressed under the roller, or it may be partially compressed, the asphalt cement then applied, and final rolling completed, as may be considered most desirable.

Assuming that Bermudez asphalt cement is the binding material to be employed, the way in which it is melted alongside the road and the temperature at which it is maintained has a very considerable bearing on the success of the work. It can readily be too hot or too cold. If it is too cold it does not penetrate into the surface nor properly coat the stone. If it is too hot it forms too thin a layer upon the stone and runs through the voids to a position which is not near enough to the surface of the road. It is very important, therefore, that the temperature of the asphalt cement or road binder should be carefully regulated with thermometers. It should never be heated above 375° F. for two reasons; the road binder may be injured thereby and is, under any circumstances, hardened rapidly at high temperatures and, for the reason given above, it may be too liquid. It should not fall below 340° F. and not as low as that in extremely cold weather. The temperature must be regulated to a certain extent according to atmospheric conditions.

The melting and maintenance of a bituminous road binder at the proper temperature will be very much influenced by the size and form of the kettles or melting tanks in which it is done. The material will be much more apt to be overheated in a small melting tank than in one of large size. It is recommended, therefore, that tanks of as large size as can be moved from place to place be used for this purpose. Agitation of some form should always be provided in order that the bitumen which comes in contact with the sides of the melting tank where they are exposed to the fire may have a proper circulation, and not be injured by remaining in contact therewith for a long time. Tanks should be available in

such numbers that a new lot of material may be melted and brought to the proper temperature before that in another kettle is exhausted. It is not good practice to add cold material to the melted supply which is being used on the road.

The distribution of the road binder may be accomplished by hand labor or by mechanical distributors. For distribution by hand various types of so-called pouring pots are available. Uniformity of distribution is dependent upon the skill of the man handling the pot. Pots with a broad horizontal orifice from which the asphalt runs in a regular stream upon the stone while the man walks backward without changing the position of the pot, apparently, do the most satisfactory work. Pots with narrower orifices, both vertical and horizontal, which require swinging the pot from side to side as the laborer retreats from the finished portion, are also in use. Uniform work has been done with these pots but they require more skill to manipulate.

Mechanical devices for the distribution of hot road binder are numerous, but there are but few of them which are suitable for distributing asphalt cements or binders made from the native asphalts owing to the higher temperature at which they must be maintained, and their greater viscosity. The material distributed from the nozzles of these appliances may be in the form of a continuous current or a spray of atomized material. At present it would be impossible to say which produces the best result with the road binders composed of native asphalts.

After the road binder has been applied to the stone it is further compressed, if the final compression was not *originally applied.* If this had taken place before the

asphaltic binder was added, broken stones or fragments, which are known as pea grit and which consist of particles passing a screen with circular openings 5/8 in. in diameter, although coarser material is frequently used, are spread in sufficient quantity to fill the voids in the crushed stone which constitutes the surface. It is well swept and rolled in. Afterward the excess is removed and another coat of bitumen is applied to seal the surface. On completion of this application a further course of grit, sand or dust, often that which has been previously removed from the road, is spread to correct the stickiness of the surface, and the road is ready for use.

The amount of a road binder made from Bermudez asphalt which is applied to the broken stone should be a gallon and a half in case the surface course is 3 in. thick, and somewhat less if it is made of smaller stone and is only 2 in. thick. In the first case the stone may be of 1 1/2-in. size, but in the lesser thickness it should be of the size of binder stone—less than an inch in diameter. The seal or grit coat should amount to something more than half a gallon per square yard of surface, and less than three-quarters. These quantities apply solely to the use of the viscous, oily, stable lake asphalt binder, and would prove too large, owing to the bleeding which would arise under the temperature produced by a summer's sun, for other materials derived from petroleum.

When the asphaltic broken-stone road is constructed by the mixing process the material is turned out in the same manner as would be the case if it were an open binder, and the same precautions must be used in doing so. As has been previously said, the danger lies in having the

stone too hot, when it will retain an insufficient coating of the road binder, or too cold when it will retain too much. The difficulty with the mixing process is that the plants available for heating the stone do it in such an irregular way and with such variations in temperature, that a satisfactory result is not obtained. This is particularly true of methods of heating the stone alongside the road in portable mixers, and the best work is only accomplished where a large semi-portable plant is available for the purpose. After spreading and placing the coated stone in position in the road it is compressed like a binder course and the pea-grit fragments and seal coat completed in the same manner as for work done by the penetration method.

Many excellent and many very poor pieces of construction have been done by both the penetration and the mixing method, and it is evident that the character of the surface which is constructed will depend entirely on the care with which the work is regulated, particularly the temperature of the stone in the mixing process and of the asphaltic road binder in both methods. Attention to detail in these directions is as necessary as in constructing sheet asphalt surface mixtures, and good results cannot be expected otherwise.

Asphalt Surface or Carpet Coats.—It has been a common practice for some time in Great Britain and on the Continent, to make an application of coal tar in its various forms to old road surfaces to mitigate or remove the dust nuisance, or to protect them from wear and disintegration. In America, where asphaltic materials, which are of a more suitable nature, are available, attempts have been made to use materials of this description for the purpose, with the idea that such applications would be more lasting than the very temporary benefits

derived from the use of tar. It was readily recognized on careful consideration and also demonstrated by service tests that asphaltic oils and residuals which contained a considerable percentage of paraffine hydrocarbons do not have sufficient adhesive and binding qualities to permit of their successful use. This excludes the possibility of satisfactorily using in the East, materials derived from petroleum found in most of the fields in the United States, supplies of which are available at a reasonable price. The asphaltic oils are preferable for this purpose and alone give satisfactory results. These asphaltic oils are found in California, in Mexico and in Trinidad. The California oils are excluded from use in the eastern parts of the United States on account of the cost of transportation. The Mexican and Trinidad oils are available at reasonable prices. The oils, although both of an asphaltic nature, are of two different types. They are both sulphur oils, and from analogy would be looked upon as closely related to the native asphalts. The sulphur in the Mexican, however, is in a different state of combination from that in the Trinidad oil and the manipulation of the Mexican material, on distillation, difficult on this account. The Mexican oil also carries from 1 to 3 per cent. of hard paraffine scale pointing to the fact that the material is not entirely asphaltic and, therefore, not as satisfactory as the oil from Trinidad. Service tests, during the short time that they have been conducted, justify the conclusion that the Trinidad oil is the more satisfactory for the production of a surface coat on an old broken-stone or gravel road, or in a new gravel surface.

Whatever the material which may be used for a carpet coat, it should be applied with a mechanical distributor

capable of handling it in a heated condition, preferably under pressure and either atomized or not.

The life which a carpet coat may be expected to have will be dependent as well on the character of the surface to which it is applied and the manner of application, as upon the kind of material. A smooth water-bound broken-stone surface is the most desirable one, and a carpet coat should be made to adhere to this satisfactorily if it is freed absolutely from dust and the oil applied at a high enough temperature in dry and warm sunny weather. If, however, this is not the case, it will be necessary to make an application of naphtha or kerosene to obtain proper adhesion of the carpet. Most of the unsatisfactory carpet coats may be attributed to the fact that the bituminous material is not applied in such a way as to permit of thorough adhesion. There is no greater enemy to proper adhesion than dust of any description. In the asphalt industry, adhesion of asphalt to packages in which the refined material is contained, is prevented by claying the surface of the package, and the same result will be found if the surface of a road is dusty. This applies as well to a hydraulic cement concrete surface as to broken stone or other form of road.

Where the dust cannot be thoroughly removed from the road surface for any reason, it is better to sprinkle it lightly with water before applying the bitumen, rather than to attempt to cover a dusty surface, as the dust and water will emulsify with the oil and adhesion will be obtained when the water dries out. This method of procedure is not always successful and can hardly be recommended as a substitute for thoroughly cleaning the road.

The amount of oil per square yard of surface should be half a gallon or slightly more than that, depending upon the smoothness of the surface. Regulation of the exact amount must be arrived at by good judgment and experience.

After the application of the bituminous material coarse sand or fine grit or gravel should be sprinkled and rolled. Fine sand is most undesirable for this purpose as it readily displaces under travel, and causes a wavy surface. The same result is brought about by the use of sand to absorb superfluous bitumen which is softened by the summer sun. A final treatment of this description is of very great importance if a lasting and satisfactory carpet is to be obtained.

The age of carpet coats will depend very much on the amount and character of the travel to which they are subjected. They are very satisfactory with motor vehicles, but iron-tired horse-drawn vehicles break them up badly. Repairs can be made where defects occur, and it is probable that the state of Massachusetts, whose records can be consulted on this subject, has had the most extended and successful experience in so doing.

CHAPTER XI

MAINTENANCE AND REPAIRS

Asphalt surfaces, like all other street and highway surfaces require maintenance, and the extent of this maintenance will depend upon the character of the original construction, the wear and tear to which the surface is exposed, and the good judgment and skill with which it is carried out. The causes of deterioration are many and are discussed at length in "The Modern Asphalt Pavement."

Maintenance is required because of deterioration and repairs for the renewal of the surface where openings have been made for underground work. In a pocket-book it will only be necessary to make some suggestions as to how maintenance can be best carried out.

In repairing cuts or surfaces which have been displaced in the course of public improvements, it is of great importance that trenches or openings disturbing the soil should be back-filled in such a way as to give an adequate support to the foundation. Of course the manner in which this can be most satisfactorily done will depend upon the nature of the soil. Sandy soils can be well compacted with the use of water, but this will not serve where the soil is of a clayey nature. The fills should be in courses of but a few inches in thickness and well rammed. Where the soil is of such a nature as to prevent an immediate compaction by ramming, a natural

settlement should be awaited before placing the surface. In winter months this will, of course, always be necessary.

The foundation placed upon the fill must be of the type of the original pavement, and carefully placed at a proper grade. It is sometimes rather ludicrous to observe the condition of an old foundation, either of concrete or stone blocks, when the surface is removed for renewal and where there have been many cuts during the life of the pavement. It will often look like a checker-board with elevations and depressions at different levels. That fills can be satisfactorily done is evidenced from replacement over trenches which have been excavated for laying large water mains, 48 in. in diameter, in old broken-stone surfaces, as on Broadway above 59th St. in New York City, but too often it is not so done and depressions in the new surface result in course of time under travel.

In the case of maintaining sheet asphalt surfaces where there is no defect in the foundation, it is usually done in one or two ways, either by cutting out the defect, removing the surface mixture and binder and replacing the entire intermediate and surface coat, or the latter alone is softened by a heater and scraped off with a saw-toothed hoe for a depth sufficient to allow the application of at least an inch of new material.

In the cutting-out process care should be taken to carry the cut back to good material which shall form a stable joint and give lateral support to the patch. The cutting instrument should be of such description that it will cut and not shatter the adjoining surface which is to remain in place. The cut should be perpendicular and not slope in toward the hole to be repaired as this will not furnish a satisfactory support. A feather edge of new material will not prove lasting. Cuts should be of

rectangular shape and not rounded, not only on account of the unsightliness of the latter but because the rectangular cut is more stable. The edges of the cut should be carefully painted with asphalt cement and not merely daubed with it here and there, as is the usual practice, owing to the use of brushes or brooms which are quite unsuited for the purpose. The coating should be as thin as possible, and a softer cement than that in use for making the surface mixture will aid in accomplishing the painting properly. The necessity for perfectly painting the joints is often evidenced by the fact that repairs show their outline when improperly done as the surface begins to dry out after wet weather.

The surface mixture which is used for the patch should have a mineral aggregate of the same grading as that of the original pavement, or approach it as nearly as possible. The asphalt cement of which it is composed should correspond in consistency to that in the old surface, which will depend upon the age of the latter, being harder for an old surface than for a comparatively new one. Too soft a mixture will readily displace when used to repair an old and hard surface. Good judgment is most necessary in determining the amount of surface mixture to be placed in any cut. It should not be so large an amount that it will project above the old surface when it has been compressed under the roller, nor so small that the roller will ride on the old pavement and thus prevent proper compression of the new material. In the latter case the patch will at first absorb water in wet weather and later, being compressed by the travel under which it is subjected, will be depressed below the surface of the street which has been repaired.

The difficulty in making repairs over large areas where

the pavements are of different ages, is the fact that the surface mixture which may be suitable for one street of considerable age and consequent hardness, may not be satisfactory for another surface which consists of a softer mixture.

In making repairs over small areas it will be found well to furnish the material from the plant in what are known as "combination loads." The forward part of the truck may be loaded with binder and the latter with surface mixture, the two being separated by an old canvas or even, very satisfactorily, with heavy Manila paper.

There are several types of surface heaters which are in use for softening the old surface. The preference for one or another merely depends upon the speed with which the work can be done and the area of old material which can be removed in a given time. In the writer's opinion, there is no superiority in the use of hot air over the direct flame method, as the lower layers of the surface are not injured by the flame if the burned and softened material is completely removed before applying the new surface. Work which has been under the author's observation and which was done fifteen years ago with a direct flame, is in satisfactory condition at the present time. Of course good judgment must be used in doing work of this description and the new surface work must be completed before the bottom course upon which it is placed has become entirely cold. It is not, in the opinion of the writer, a desirable thing to apply a paint coat to the burned surface unless the cuts which have been burned out have become quite cold, as for instance, *by not being filled* until the day following that on which

they have been made. Such an application of paint will frequently act as a lubricator and cause displacement.

Repair work should not, of course, be done in wet or cold weather. Frequently much criticism is heard of the fact that the repairs are not immediately made to old sheet asphalt surfaces which have deteriorated rapidly during cold or wet weather in winter, but it would be injudicious in the light of the author's experience, to attempt to do such repairs under unfavorable conditions. There are often winters which are dry and cold during which repairs can be undertaken at all times, and others in which it is impossible to do good work and inadvisable to attempt it. Under any circumstances repair work requires great skill, long-time experience on the part of foremen and laborers in executing it and good judgment as to what to replace and when to do it.

Maintenance and repairs to broken-stone roads require as much care and good judgment as those to sheet asphalt surfaces. In the writer's opinion, spots that have disintegrated or become depressed, should be cut out in quite the same way as in a sheet asphalt surface, in order to obtain the proper lateral support for the patch. The cut should be filled with the same character of material as that which was used in the original construction of the surface, and not with coarser or finer material, as is sometimes done.

As yet the application of surface heaters to the repairing of bituminous broken-stone or concrete roads has received very little attention. There seems to be no reason why heaters should not be used if the highest type of work is desired.

CHAPTER XII

THE PLANT

To produce a satisfactory material from the components which are available for use as a road surface, some type of plant which shall meet certain imposed conditions is necessary. Provision must be made for heating the sand and stone with great regularity and uniformity without segregation, to such a temperature as will enable it to be satisfactorily mixed with an asphalt cementing material, to melt asphalt, heat flux and produce asphaltic cement, and maintain the latter in a melted condition at a uniform temperature with suitable means of agitation, to afford suitable means of determining the weight and volume of the constituents which are to compose the different batches of the material and to provide a mixer which shall combine the components uniformly and homogeneously.

It would hardly be justifiable to go into a description of the various types of plants which are available for this purpose at the present time. Many of them comply with the requisites which have been laid down. The important point to be considered is: they should be of such capacity as to furnish adequate supplies of all the components which are to be used, and in such quantities and in such condition that no delay shall ensue in meeting the demands of the mixer. The sand should be heated in a uniform manner and after collection in a storage bin *should* have the proper temperature, neither too hot nor

too cold, the extreme in cold weather being not over 380° F. and in warm weather not below 325° F. The success with which sand is heated will depend largely on the skill of the fireman who manipulates the fires, and the output should be carefully watched as to temperatures by means of thermometers. The plant should possess sufficient storage capacity for hot sand in the way of bins, so that it can be accumulated in considerable amounts before proceeding to turn out surface mixtures, as this will not be done satisfactorily if delays are incurred while waiting for a supply. Care should be taken to see that in passing through the sand drums and in storing it in the bins, segregation does not take place; that is to say, that the coarser particles do not collect at one point and the finer ones at another, thus preventing uniformity in the sand grading as it is supplied to the mixer.

In case asphaltic concrete is turned out provision must be made for separating the heated stone into at least two sizes. This can be accomplished by passing the stone as it comes from the drums over revolving screens having a pitch of 3/4 in. to 1 ft., and 6 ft. long, 3 ft. of which is covered with metal perforated with 1/8-in. openings to separate sand, and the other 3 ft. with 3/8-in. perforations to separate stone of small size, the tailings consisting of the larger stone. The three sizes of aggregate are then combined in the required proportion by weight or measurement.

It is usually advisable, however, not to heat the stone and sand in the same drum, as under such circumstances the stone becomes much too hot by the time that the sand is heated to a sufficient temperature. It is preferable to heat the stone and the sand separately.

The tanks for maintaining the asphalt cement in

melted condition should be so constructed that no portion of their contents will become overheated at any point, although this should ordinarily be avoided by suitable agitation, as has been mentioned in the chapter on asphalt cement. With smaller portable tanks, where asphalt is melted alongside the road as in bituminous highway construction, and where no power agitation is possible, agitation by hand should always be provided.

In permanent plants of the highest grade the asphalt is melted and fluxed in tanks which are provided with coils of pipe carrying steam under high pressure, 125 lb. to the square inch, and the agitation is dry steam. This permits of fluxing asphalt at a moderate temperature and of maintaining it in the same way for a considerable period of time without danger of its becoming harder in consistency. The tanks from which the asphalt is dipped and measured for use in making surface mixtures are filled from those which are heated by steam. The dipping tanks should be fired carefully and should be cleaned at intervals from any sediment forming upon the bottom, not only for the reason that it preserves the tank itself but also admits of lighter firing to maintain the asphalt cement at the proper temperature and consequent reduction of the danger of overheating the material.

The character of the mixer in use in combining the hot components is of great importance, and equally so the fact that it must be maintained in the best condition. It should have a liner which can be replaced when worn and the teeth should always be maintained of such length that they are not separated from the liner by more than a quarter of an inch in the case of the surface material, although a wider space must be provided where a mixture containing or consisting of stone is provided. This can

be regulated by the introduction or removal of shims under the bearings of the shaft upon which the teeth are fixed, as may be necessary.

The best practice provides for the use of one mixer for producing surface material and another for stone mixtures, such as open and close binder or asphaltic concrete. Where this is not the case an interchangeable shaft must be provided which has teeth of a proper length for the stone mixture to replace those in use with the sheet asphalt mixture.

Provision must be made for the proper storage in a perfectly dry condition of the supply of filler, and provision made for measuring it, usually by volume.

All the components in the mixture should, preferably, be weighed, but it is usual to confine this to the asphalt cement, the sand being measured by volume, the weight of which is known, and the filler in a similar way.

The proper volume or weight of sand, the temperature of which has been shown to be satisfactory by a thermometer, is introduced into the mixer, and immediately followed by the proper amount of filler. The sand and the filler are allowed to mix for at least fifteen seconds. After the mixture of the two is homogeneous and the filler has attained the temperature, or approximately so, of the sand, the weighed amount of asphalt cement is added, and the three components mixed for thirty seconds, or longer, and until the material is homogeneous.

The character of the material which is turned out will depend as much on the skill of the foreman who is managing the plant as upon the plant itself. The writer has seen better mixtures produced by a skillful foreman with a very poor plant than by a careless one in the best type of plant. Constant vigilance is necessary

to control the character and temperature of the components which are going into the mixture. To insure the most satisfactory results the plant should be provided with facilities for so doing, for the use of the yard foreman, adjoining the platform on which the mixing is done, or nearby. Thermometers for taking temperatures must be available. A set of sand screens should be at hand for controlling the sand grading; a proper outfit, either a penetration machine or a float plate, for controlling the consistency of the asphalt cement, and Manila paper suitable for making pat tests of the mixture, in a manner previously described, so that he can control the amount of asphalt cement in use. Very frequent tests of grading of the sand, its temperature, the consistency of the asphalt cement and the amount in the mixture, should be conducted. Such tests cannot be neglected if the output is expected to be satisfactory and uniform, and this is recognized as seen from the directions of a concern given in the "Instructions for Plant Foremen and Chemists" which have been previously quoted.

In the production of the binder, whether of the open or close type, the same care must be exercised. In producing open binder the stone should not be too hot so that the asphalt cement will run off it on hauling to the street. The production of asphaltic concrete, whether for use as a close binder or for a surface course, requires greater care, involving all the considerations entering into the preparation of the ordinary type of sand mixture, but sufficient has been said in regard to this in another chapter to show its importance.

CHAPTER XIII

WORK UPON THE STREET

The material produced at the plant, whether binder or surface mixture, must be transported to the street in such a way as to preserve as nearly the same temperature that it had on leaving the plant. To accomplish this canvas covers should be provided for the trucks in which the material is hauled. That it has the proper temperature must be determined with a thermometer on its arrival at the street, and the street foreman should be convinced that the temperature is satisfactory before he puts it in place. Usually the larger the amount of material contained in a load the better the temperature will be preserved but, on the other hand, the larger the load the more it becomes compacted during its haul to the street, and the more difficult it is to break it up and rake it out. The disadvantage, in this direction, of large loads must be considered, especially if the hauls are long. A sheet asphalt surface mixture or an asphaltic concrete will, of course, suffer more in this way than an open binder. Under any circumstances the most important consideration in laying a street surface is to see that the mixture or close binder is completely loosened up and spread evenly with rakes before the use of the roller is permitted. The waviness which is so common in many bituminous surfaces is due to the fact that the hot material is not completely raked out. Mixtures should be dumped so far from the point where they are to be placed

eventually, that they must be entirely shoveled over. Rakes with long teeth should be used, and every portion of it loosened up so that no lumps of compacted material remain. The workmen should not be allowed to walk or place their feet in the hot mixture for the purpose of reaching out to correct some defect. Such depressions will be filled by the raker, leaving more material at these points than elsewhere. Under travel the more slightly compressed material will be depressed, and unevenness in the surface of the work will eventually become apparent. In the extended experience of the writer, a satisfactory result will only be obtained by constant attention on the part of the street foreman to these conditions. The care expended on supervision and regulation of the distribution of the hot material will give a return which cannot be accomplished in any other way.

The temperature of a surface mixture on the street should be not less than 300° F. for one prepared with Bermudez asphalt. A Trinidad mixture may be laid at a temperature of from 325° to 340° F. more satisfactorily, at least if it has a dense mineral aggregate, although some of the poorer mixtures in each case may undoubtedly be laid at much lower temperatures.

If a sheet asphalt surface contains a sufficient amount of filler and if the sand is of a satisfactory grading, the original compression of the material may be carried out at once with a steam roller, as such a mixture will not displace under it, but with some of the coarser mixtures a lighter roller may first be necessary.

The rolling and compression of a sheet asphalt surface require great experience and skill on the part of the roller engineer in order to produce a satisfactory surface but such a person cannot obtain satisfactory results if the

materials have not originally been distributed by the rakers with great care. It is impossible here to give in any adequate manner a description of how rolling should be done. It is something that must be acquired by experience. It is needless to say that the roller should be so manipulated as to produce no waves in the pavement, which will often happen if the roller is stopped or started suddenly. Where the width of the street permits, cross rolling as well as longitudinal should be practised. It is questionable if it is desirable to roll a sheet asphalt surface too much after it has cooled to a certain point. Travel will accomplish the necessary compression after the street has been opened, and without danger of producing some of the defects which may be attributed to the steam roller. It must be remembered that the weight upon the iron tires of a truck is greater per inch tread than that of the steam roller, which is so widely distributed per inch run. Travel and traffic will, therefore, accomplish much which the roller cannot. As has been said, travel over a sheet asphalt surface will bring out many of the defects which are not visible after the steam roller has finished its work.

Provision is frequently made that cement or limestone dust be scattered over the surface before it is rolled, and that the gutters be painted for a certain width with asphaltic cement. In the experience of the writer in England and on the Continent, both of these provisions involve expense with no adequate return. The surface can be rolled as satisfactorily without dusting, and perhaps more so. The desired color of the surface will be produced by a few days travel of vehicles and by the natural dust which accumulates there. A paint coat on the gutters, where the mixture

is satisfactory, is quite unnecessary and involves a useless additional expense. Modern asphalt mixtures are not susceptible to water action if proper provision is made for grades so that water will not stand in pools for any length of time, and this, of course, is something that the municipal engineer should provide for. The gutters on lower Fifth Avenue, New York, have been exposed to travel and the elements for fifteen years, and show no signs of deterioration.

Finally, a warning must be given against the use of hot smoothing irons upon a sheet asphalt surface. The closing up of any slight porosity will take place under traffic, whereas the smoothing irons, while closing up such places do very serious damage to the surface with which they come in contact. Their use should be abandoned as it is merely an excuse to cover up poor work. This should be prevented in some other way.

CHAPTER XIV

ADVICE TO ENGINEERS, CONTRACTORS AND INSPECTORS

Suggestions to Engineers.—Based upon an extended experience in the construction of asphalt surfaces, the writer would suggest to engineers that in preparing specifications they be made as simple and as free from verbiage as possible, to avoid difficulties in their interpretation. Frequently they carry expressions which have been handed down from year to year through a series of specifications and which, in the light of modern practice, have little or no meaning. Clauses which can be interpreted in different manners should be eliminated. Materials should be specified specifically. For example, a specification should not call for Portland cement or ground limestone as a filler, the alternative materials being of very different value and cost. In any contract only one should be provided for. It would be as absurd to permit the use of a natural or Portland cement concrete foundation as the permissible use of one or another filler. The same may be said in regard to permitting bids on different asphalts of different origin and value. The engineer should know which type of material he desires, whether one corresponding to Portland cement or that corresponding to a natural cement. Unfortunately local legislation does not usually permit of this and the result is that that locality

where the contract must be awarded to the lowest bidder gets the cheapest type of construction instead of the best. As long as such laws remain on the statute books the highest type of construction will not be attained. The locality will obtain a pavement which corresponds to a $3 pair of shoes instead of one corresponding to a $5 pair.

The engineer should base his specification on service tests and experience in the construction of asphaltic surfaces. If not of extended experience himself he should be guided by that of others, accommodating their results to the local conditions which he must meet. Standard specifications of various societies may be used as a guide, but not blindly. As has been said in another chapter, the type of surface constructed should be designed for the condition which it is required to meet. Under the most trying conditions an expensive pavement may, eventually, be more economical than a cheaper form, whereas under others the reverse may be the case. Good judgment is, therefore, essential in deciding upon what is to be called for.

The engineer, unfortunately, is not always given the widest liberty in laying down the policy to be followed, but must accommodate himself to the ideas of officials over him who have little knowledge of pavement construction. It must be remembered that the economic value of any pavement will not be demonstrated until the pavement is worn out. It is only then that a determination is arrived at as to how many tons of travel the surface has carried during the period of its existence, and what this has cost. The paving problem is one extending over a long period of years, and that locality will be best served which gives its engineer such tenure of

office that he can follow it through a long period of time. The short tenure of office of many of our municipal and state highway engineers is responsible for changes of policy at intervals which are destructive of economy.

Tests for materials should be so prescribed that only the material which the engineer desires will comply with them. It would be foolish to write a specification for cement which would admit both Portland cement and natural cement. It seems equally so to write a specification for asphalt which will admit with the highest grade material some of the lower priced industrial residuals. The engineer should decide what he wishes and specify either one or the other, in the case of asphalt as well as in the case of hydraulic cement. Unfortunately, public opinion, and the law in many cases, do not recognize this fact and the result is great confusion in many specfiications which are drawn, and in the subsequent awarding of a contract of which they form a part. Education of the public in this respect is most necessary, and it is the engineer who can undertake it most satisfactorily. Before specifications are issued, all persons, contractors, citizens and others, should have an opportunity to see and discuss them and make objections to them, to insure their reasonableness.

Suggestions to Contractors.—A contractor who engages in the construction of sheet asphalt pavements and asphaltic concrete or broken-stone highways, should put himself in close relation with the engineer who draws the specifications and should, where it is possible, enter any objections to them before they have been advertised. The combined judgment of the two should result in a specification which can be carried out satisfactorily in a practical way without arousing contention. The engineer

can name what he wishes, and the contractor can tell him what it is possible for him to do with satisfaction.

The contractor, if he wishes to remain in the business for an indefinite period, and to establish a reputation for doing the best work, will take pride in seeing that the specifications are closely complied with, and that the asphaltic surface which he constructs will be a credit to him, not only for the period during which it is under guarantee, but for years afterward. He should see that a surface laid under a five-year guarantee will not only go through this period with a low cost of maintenance, but shall continue to do so for many years afterward. On the other hand, the contractor is frequently hampered by rulings of the engineer or his inspectors, through the latter's ignorance. Cases have come to the attention of the writer where attempts or willingness of the contractor to do better work than the specification called for, have not been appreciated, and such work has even been ruled upon as not complying with the specifications on this account. The contractor must, therefore, in many instances, confine himself absolutely to the terms of the contract where, by increasing somewhat the cost to himself he might do a much better job, and one which would be more to his credit. In every case, of course, the contractor must so conduct his operations as to avoid any possibility of litigation and the hair-splitting which is too often the object of an engineer or inspector who desires to demonstrate his own importance.

Suggestions to Inspectors.—It is the duty of the inspector to observe, for the benefit of the engineer, the character of the materials which enter into any piece of asphaltic construction over which he may be placed, and the workmanship and manner in which they are

put in place but he should be a tactful man and aid rather than hinder the contractor in his work, reporting to the engineer any defects in materials or workmanship which he has observed, but rarely attempting to give direct orders to the contractor or his employees. His dealings with the latter should be more in the nature of suggestions than orders. The orders should come directly from the engineer or from his immediate assistant. Inspectors when they use their authority along these lines may be of the greatest assistance to both contracting parties, but otherwise a great hindrance. The inspector should be thoroughly informed in regard to the character of the materials in use in any piece of work which he is supervising, and in regard to the form of construction employed. It is for the purpose of instructing him in this direction that the present work is prepared.

Suggestions to Citizens.—It may be suggested to the citizen that the economics of pavement and highway construction is a subject which should be carefully considered before that of the actual cost at which any piece of work is done. The citizen, as a rule, does not appreciate that a sheet asphalt surface, for instance, which may cost under a certain specification 50 cents a square yard more than another under a different specification, is really more economical than the cheaper form. The illustration which has been used before, comparing the two surfaces to shoes which cost $3 and $5 per pair, may again be used. The more expensive materials in the dearer shoes will give more lasting and more economic results than those obtained with the inferior material. Of course, there are conditions under which the cheaper material may be employed

economically, comparable for instance to a situation where the shoes would be subjected to only slight wear and tear, or where the locality is so situated financially as not to permit of the purchase of a high-grade material. If a city's streets were in the hands of a business manager with a permanent tenure of office, and he was responsible for the financial result after a period of twenty years, it would seldom be the case that the least expensive form of pavement would be constructed. There is nothing which contributes so much to the unsatisfactory results obtained in many localities as the necessity for accepting the lowest bid for construction work. The selection of the type of pavement and the contractor who will do the work should be left to the judgment of the engineer, if he is a man of ability and good judgment, and is to retain his tenure of office for a long period of time. Unfortunately these conditions rarely exist and the public are the victims of the present situation, which is not one which would be tolerated by a private corporation.

CHAPTER XV

LABORATORY

At a plant which is to provide material for any large area of work a laboratory should be provided for purposes of control, and some one, chemist or inspector, should be available who should be experienced in the use of the apparatus. Such a laboratory can be installed at very moderate expense, and involves the purchase of the following apparatus:

1 Chaslyn balance, Eimer & Amend No. 2171.

1 Baker's scale, Eimer & Amend No. 2148.

2 Bunsen burners, E. & A. No. 2597 (see note).

1 set sieves—200, 100, 80, 50, 40, 30, 20, 10, 4 and 2 mesh, (Howard & Morse, Brooklyn, N. Y.).

2 thermometers for penetrometer, 212° F., E. & A. No. 4894.

1 doz. 2 1/2-in. glass funnels, E. & A. No. 3345.

1 doz. watch glasses to cover funnels, E. & A. No. 7189.

1 doz. Erlenmeyer flasks, Jena glass, 200 c.c., E. & A. No. 3863.

1 N. Y. Testing Laboratory miniature penetrometer, Howard & Morse, Brooklyn.

1/2 doz. 4 1/2-in porcelain evaporating dishes, E. & A. No. 2963.

1/2 doz. watch glasses to cover dishes, E. & A. No. 7189.

1/2 doz. Royal Berlin porcelain crucibles No. 0, without covers, E & A. 2850.
4 Royal Berlin crucibles No. 2, without covers, E. & A. No. 2850.
4 packages filter paper, S. & S., No. 597, E. & A. No. 3213 (9 cm.).
1/2 doz. porcelain Gooch crucibles (40 c.c.) E. & A. No. 2852.
1 pair tongs, E. & A. 2883-B.
2 iron ring stands, E. & A. No. 4812.
2 iron sand baths, 6 in. deep form, E. & A. No. 4555.
1 spatula, 4 in. E. & A. No. 4643.
1 spatula, 6 in. E. & A. No. 4643.
1 spatula, 8 in. E. & A. No. 4643.
1/2 lb. asbestos for Gooch filters.
3 clay triangles, small, to fit R. B. crucible No. 0, E. & A. No. 4965.
3 clay triangles, large, to support porcelain evaporating dishes, E. & A. No. 4965.
1 N. Y. Testing Laboratory drying oven, E. & A. No. 2073-d (see note).
1 gross 3 oz. deep seamless tin boxes, E. & A. No. 2482.
1 gross 2 oz. seamless tin boxes—E. & A. No. 2482.
2 chemical thermometers—600° F., E. & A. No. 4882.
1/2 doz. camel's hair brushes, large size, E. & A. No. 2493.
1 Cleveland cup oil tester, E. & A. No. 4162, gas or alcohol lamp.
1/4 lb. glass tubing, 3/16-in. diameter.
1/4 lb. glass rod, 1/8-in. diameter.
1 *washing* bottle, 1 quart, E. & A. No. 7181.

50 lbs. carbon disulphide.
10 ft. rubber tubing, 5/16 in., E. & A. No. 4540.
1 drum for carbon disulphide.
1 N. Y. Testing Laboratory extractor for asphaltic concrete, Howard & Morse.

Note.—If a gas supply is not available, substitute two Barthel's alcohol burners, E. & A. No. 2544, small, for the Bunsen burner and tubing; also omit drying oven No. 2073-d.

The methods which should be employed in utilizing this apparatus are ordinarily few in number and do not demand extreme skill but rather a certain amount of experience on the part of the operator. They are described in numerous publications, and will be found in the writer's work "The Modern Asphalt Pavement." Those which are in use in ordinary control work are given in the next chapter.

With such a laboratory available there should be possible a control of the consistency and uniformity of the asphalt cement, of the percentage of bitumen and grading of the mineral aggregate of the surfaces mixtures which are turned out, as well as the supplies of sand and of the raw materials which are received at the plant. Without such a laboratory the highest type of work cannot be accomplished.

CHAPTER XVI

METHODS FOR EXAMINATION OF BITUMINOUS MATERIALS AND MINERAL AGGREGATES

Mesh Composition of Mineral Aggregate.—The determination of the grading of sand or of the fineness of a filler, is done with a series of sieves, which have been described on page 26. The operation of sifting and weighing the sand is conducted as follows:

From 50 grm. to 500 grm. of the sand or crushed stone is weighed out on a satisfactory balance sensible to half a gram. It is thrown upon the 200-mesh sieve, the openings of which have been previously freed from very fine particles with a stiff brush. It is shaken from side to side, held in one hand and striking it between each movement against the palm of the other hand, and hitting it sharply on the table or on a hard surface from time to time to dislodge any particles which have filled the meshes but will not pass through. The sifting is done over a clean piece of paper to determine when further particles fail to pass the sieve. Any lumps of material which readily break up under the fingers should be so treated. When nothing further passes the sieve it will be found that some material will remain in the meshes of the wire cloth. This is allowed to remain there as being more nearly the size of the grains passed by this sieve than the next larger. It is rejected when the cloth is brushed for the next use of the sieve. The percentage of material passing the 200-mesh screen is

arrived at by weighing the portion which will not pass and deducting this from the original weight, 50 grm., from which the percentage of this material may be readily calculated.

The 200-mesh screen is used first for the reason that the fine material must necessarily be removed first from the coarser particles to which it may adhere, and because some of it may be lost by blowing away in the process of sifting. It is determined by the loss of weight rather than by direct weighing, for the same reason. In sifting fine material to be used as a filler, some coarse material should be placed in the sieve, such as a few pennies or some shot, to aid in breaking up the lumps and assist in screening.

After the use of the 200-mesh sieve the others are employed in order of size, and the percentage passing each of the screens determined by the loss in weight which occurs.

The grading of the mineral aggregate of sheet asphalt mixtures is determined in the same way as that of sand, after the removal of the bitumen by solvents.

Where the aggregate carries coarser material than sand, this is usually removed by separating it with a 10-mesh sieve before screening the finer portion, as the coarser particles would injure the cloth of the finer sieves.

The entire operation can be carried out by mechanical contrivances, and this is frequently advisable with the coarser aggregates but is not so satisfactory, in the author's opinion, with those which are finer and which are found in a sheet asphalt mixture.

Material Finer than that Passing 200 Mesh in a Filler.—The actual fineness of the dust of the filler cannot be determined solely by the use of a 200-mesh

screen, as such a screen allows the passage of particles of sand which are not fine enough to be considered a filler. The finer material can, however, be determined by elutriation with water. Five grams of the filler are placed in a beaker holding about 600 c.c. and about 120 mm. high. The beaker is nearly filled with distilled water of a temperature of 68° F. and agitated with an air blast until the filler is suspended, avoiding a rotary motion of the water. On stopping the blast the liquid is allowed to settle for fifteen seconds, when the water is poured off as quickly as possible without carrying any of the sediment. The washing is repeated twice. The residue is then washed out into a dish, dried and weighed. The loss represents the impalpably fine material which will serve as filler.

Total Bitumen in Refined Asphalt and Asphalt Cement. —One gram of the dried or refined material, in a state of fine powder, if possible, is weighed out and introduced into a 200 c.c. Erlenmeyer flask of Jena glass and covered with about 100 c.c. of carbon disulphide. It is then set aside for at least five hours, or overnight, at the temperature of the laboratory. In the meantime a Gooch crucible is prepared with an asbestos felt and weighed. The felt is made by beating up long-fiber Italian asbestos in a mortar, and suspending the finer particles in water and quickly pouring off from the coarse particles. Too much of the latter should not be removed, or the felt will be too dense. The decanted asbestos and water can be kept in a bottle for use. To prepare the felt the asbestos and water are shaken up and what is found to be a proper amount poured into the crucible, which has in the meantime been attached to a vacuum filtering-flask by the proper glass and rubber

connections. As soon as the asbestos has somewhat settled the vacuum-pump is started and the felt firmly drawn on the bottom of the crucible. It is then dried, ignited, and weighed.

After standing a proper time the disulphide is decanted very carefully upon the filter which is supported in the neck of a wide-mouth flask and allowed to run through without pressure. The flask after being tipped to pour the first portion is not again placed erect in order to avoid stirring up the insoluble material, but is held at an angle on any suitable base, such as a clay chimney. After all the disulphide has been decanted more is added and the insoluble matter shaken up with it. This is allowed to settle and decanted as before, the insoluble matter being finally brought on the filter and washed with the solvent until clean. The excess of disulphide is allowed to evaporate from the Gooch crucible at the temperature of the room. It is then dried for a short time at 100° C. and weighed. The loss of weight is the percentage of bitumen soluble in CS_2.

In the meantime, however, the disulphide which has passed the filter is allowed to subside for twenty-four hours, if possible, and is then decanted carefully from the flask in which it has been received into a weighed platinum or unweighed porcelain dish. If there is any sediment in this flask it must be rinsed back into the Gooch crucible with disulphide and the crucible again washed clean. The solvent in the dish is placed in a good draught and lighted. When all the disulphide has burned, the bitumen remaining in the dish is burned off over a lamp and the mineral residue, which was too fine to subside, is weighed, if the burning was done in a platinum dish, or dusted out and added to the crucible

if in a porcelain one. In the former case the weight is added to that of the Gooch crucible or subtracted from the per cent. of bitumen, found without its consideration, as a correction. Care must be used in this method of procedure that the solvent does not creep over the sides of the crucible and that the outside is free from bitumen before weighing.

Mineral Matter or Ash.—One gram of the same sample of material used for the determination of bitumen is weighed out in a No. 0 Royal Berlin porcelain crucible and burned in a muffle or over a flame until free from carbon. This must be determined by breaking up the cake of ash, moistening with water or alcohol, and observing if any black particles of coke are present. The weight of the residue is stated as inorganic or mineral matter.

The determination is of course not exact, sulphuric acid and the alkalies being volatilized in many cases, but it is satisfactory for technical purposes.

Consistency or Penetration of Asphalt Cements.—The consistency of an asphalt cement is determined by the depth in hundredths of a centimeter to which a No. 2 cambric needle will penetrate in five seconds, under a weight of 100 grm. at 77° F. The Dow penetration machine or the New York Testing Laboratory penetrometer may be used for this purpose, the results being the same with either, the latter being, in the opinion of the writer, more satisfactory because of its greater stability and the greater ease with which the surface of an asphalt cement is brought in contact with the needle. The asphalt cement is contained in an open box similar in shape to those in which shoe blacking is usually supplied, *at least 2 1/4 in.* in diameter and of sufficient depth to

permit of the penetration of the needle without reaching the bottom. Before being placed under the needle the surface is perfected by melting and brought to the proper temperature by immersion in water at 77° F. for a sufficient length of time to acquire this temperature. It is placed upon the support of the penetrometer, the needle brought nearly in touch with it, and then elevated by the screw until contact is attained. The needle with its weight is then released by a movement of the clamp and the time limit marked by a metronome, or otherwise. Before releasing the needle the height at which it stands is read off upon the dial with which the instrument is provided, and the drop again measured after penetration, on the same scale. Some experience is necessary in using the apparatus satisfactorily, but it can be readily acquired.

Flow Test.—The consistency of asphalt cement can be controlled, as has been said in a previous chapter, by means of comparing the length to which a cylinder of it will flow with that of a material of standard consistency. The cylinders are made in a split mould of turned brass. They are 3/4 in. long and 3/8 in. in diameter. They are placed on a brass plate with corrugations corresponding in size to that of the cylinder, being careful to see that they adhere thereto so that they will not slip when warmed. The corrugated plate is then exposed at an angle of 45° to a temperature at which the cements will flow. The relative lengths which the standard and the asphalt cement to be tested reach, is an indication of how nearly the consistency of one corresponds with that of the other. If the cement is harder than the standard it will not flow so far; if it is softer it will, of course, flow further.

Examination of Sheet Asphalt Surface Mixtures.—Specimens of sheet asphalt surface mixtures are examined

as regards the percentage of bitumen and the grading of the mineral aggregate as follows:

The amount of bitumen is determined with the laboratory equipment which has been suggested by placing 10 grm. upon a Schleicher & Schüll 9 cm. 597 filter paper folded in a funnel 2 1/2 in. in diameter with a short stem, supported in a conical flat bottom assay flask holding about 250 c.c. With a washing bottle provided with two tubes through its cork, one reaching to the bottom of the bottle and the other only just passing the cork, but with a capillary orifice, a small stream of disulphide of carbon can be delivered on inverting the flask without the necessity of using pressure from the mouth and inhaling the noxious vapor of the solvent. With this bottle a fine stream is directed on the surface mixture but no more than it can absorb. It is allowed to stand until it has softened and settled upon the filter. The latter is then filled up to an eighth of an inch below the rim and the funnel covered with a 2 1/2-in. watch-glass. It is not filled up at first, as before the mixture has been softened and settled upon the paper the solvent would have run through the filter paper and would not have been used economically. As the percolation goes on the solvent is renewed and if it goes too slowly the rate may be hastened by washing between the paper and the funnel with disulphide, which will dissolve the bitumen, which may have hardened and closed the pores by evaporation, or by lifting the filter a little and letting it drop back. On the day the analysis is started the sand is washed as clean as possible, but nothing more is done. The filter with the sand and the percolate is allowed to stand over night to permit anything that has run through to settle out.

In the morning the funnel is placed in a clean assay flask and the percolate is carefully decanted into a correction bottle, being careful not to disturb the sediment.

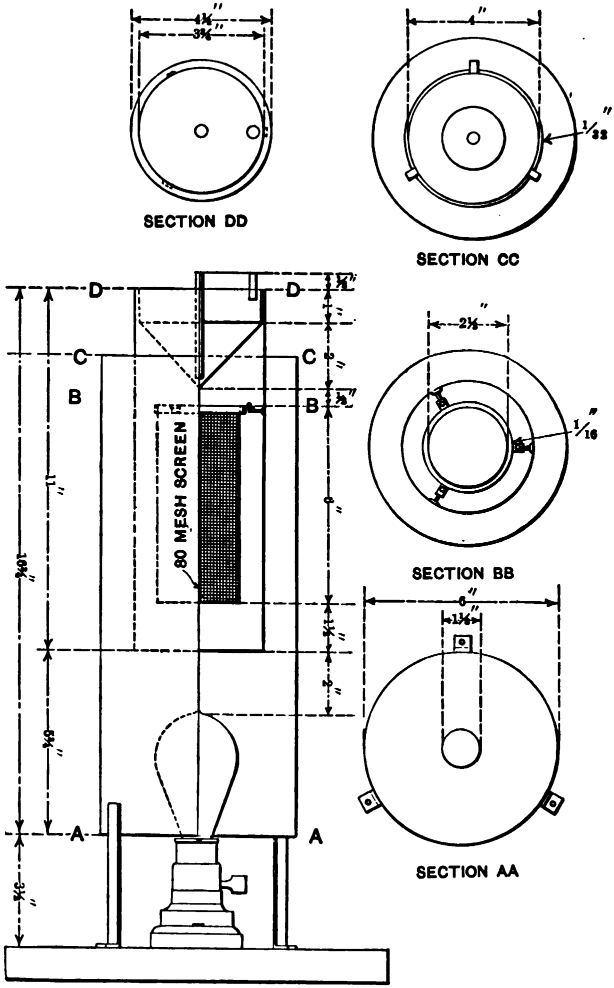
Some disulphide of carbon is poured on this, it is shaken up and poured back on the filter, the first assay flask being thoroughly cleaned with a feather and everything brought upon the original filter paper. The mineral aggregate is washed clean with the solvent.

The percolate, or solution of bitumen, in disulphide of carbon is poured from the correction bottle into a dish, burned, ignited, and the correction obtained.

In the meantime the mineral aggregate after drying is separated from the filter over a piece of glazed paper by scraping with a blunt spatula or rubbing between the fingers in an appropriate way until all the mineral matter that can be removed is separated, taking care, of course, not to detach any fibers of the paper. It is then dusted into a weighed No. 2 Royal Berlin porcelain crucible and set aside. The filter paper, containing much fine mineral matter in its pores, is burned either with the correction in its dish or in any satisfactory way, its ash and the correction added to the mineral aggregate and the crucible's entire contents, after one is assured that no trace of solvent remains, are weighed. The difference in the weight of the aggregate and the 10 grm. of surface taken is that of the bitumen and gives the per cent. of bitumen in the mixture, which should be calculated to the nearest tenth of 1 per cent.

The grading of the mineral aggregate is readily determined with sieves in the same manner as that of sand.

Examination of Asphalt Block Mixtures and Asphaltic Concrete.—In the case of mixtures carrying stone a


SECTION DD
4"
1/32"
SECTION CC
D
D
C
C
B
B
80 MESH SCREEN
11"
2½"
1/16"
SECTION BB
6"
A
A
SECTION AA

different method of procedure is necessary than with the sheet asphalt surface mixture. The following one has been devised by Mr. C. N. Forrest of the New York Testing Laboratory.

The quantity of stone mixtures which should be taken for analysis will depend upon the size of the largest particles of the mineral aggregate. The sample should be warmed until it is sufficiently soft to be readily broken apart by hand without fracturing the stone; 200 to 300 grm. of asphalt block or similar mixtures and 500 grm. of asphaltic concrete is an appropriate quantity for the analysis.

The New York Testing Laboratory extraction device, shown in the illustration on page 138 is a modification of the Wiley extractor. It is manufactured by Howard & Morse, Brooklyn, N. Y. The sample for analysis is packed in the wire basket and covered with a mat of absorbent cotton 1/4 in. thick. Place 100 c.c. carbon disulphide in the interior vessel *B.B.* and suspend the wire basket containing the sample from the hooks in the upper part of that portion of the device. The condenser *D.D.* covers *B.B.* loosely and cold water should be circulated through it. A 16-candle-power incandescent lamp in *A.A.* will vaporize the solvent which thereby rises to the condenser and falls back upon the sample extracting the bitumen therefrom.

About three hours are required to effect complete extraction, after which the solvent is permitted to evaporate from the mineral aggregate spontaneously and finally, completely expelled by warming in an oven.

The extract is burnt in a porcelain dish and the mineral matter thus recovered, which had passed through the wire basket.

The combined weight of this correction and the mineral aggregate in the basket, less the quantity taken will give the amount of bitumen present in the sample.

The extracted mineral aggregate may then be screened as previously described.

The methods which have been described are those which will be ordinarily used at the plant to control its output. Other necessary determinations must be made in a well-established laboratory, and descriptions thereof at length are given in the author's work "The Modern Asphalt Pavement" and elsewhere.

CHAPTER XVII

INSTRUCTIONS FOR TAKING SAMPLES AND SPECIMENS OF MATERIALS FOR EXAMINATION

Samples and Specimens.—To begin with, it must be explained that *there is a decided difference between a sample and a specimen of any material.* A specimen is some of the material selected to show its prominent characteristics, either of an inferior or desirable nature. A sample, if properly taken, indicates the average composition and character of the material it represents.

Specimens are preferable to samples in certain instances and the reverse. When it is desired to emphasize the peculiarities of some material, a specimen is needed; but when a quantitative determination of its characteristics is to be made, a sample is necessary.

This distinction must be borne in mind in selecting materials for examination, and good judgment must be used in regard to the most satisfactory means of arriving at the desired end.

In preparation for the construction of an asphalt pavement the materials to be used should be carefully examined.

Ordinarily the character of the rock which is to be used in the concrete and in the intermediate course, or surface, can be determined by mere inspection. The Portland cement will usually be examined and approved by the local authority and, in any case, the contractor

will obtain it from the manufacturer under a guarantee that it complies with the local specifications.

The materials which require careful inspection for use in the binder and the surface mixture of a sheet asphalt pavement include the sand, dust or filler, refined asphalt, and flux. After the work is under way the asphalt cement as used and the surface mixture itself must be subjected to close control.

Sand.—In order to select a proper supply of sand all of those which are locally available should be examined by screening and for this purpose 2 or 3 lb. should be sent to the laboratory tightly packed, so that no fine material can be lost, in a box of the size holding fifty cigars. Samples of the sand in use on the platform should be sent to the laboratory until it has been determined that the grading is running satisfactorily.

The sampling of sand must be carefully done in order to properly represent the material. The following directions are taken from "The Modern Asphalt Pavement."

Sampling Sand.—First. From Pit or Bank. It must be borne in mind that in a pit or bank the sand lies in layers of different grading, which can almost never be taken out separately as a source of supply. Experience has shown that the best that can be done is to obtain a supply representing the average composition of the face of the bank. It is useless, therefore, to send specimens of sand from strata that cannot be isolated; or, if they are sent, specimens of the other layers in the bank should accompany them, with a statement of their relative thickness. A proper sample can be obtained by cutting a groove down the face of the bank and collecting the material in a pile and sampling as described below.

Second. From Rivers or Lakeshores. In case it is

desired to sample sands from river bottoms or lakeshores, it is impossible in ordinary cases to send in more than what is considered to be a representative specimen of the material, and final sampling must await deliveries on scow or car.

Third. Deliveries of sand should be sampled as follows: Small scoopsful or shovelsful are taken from different parts of the pile, car, or boatload, and at different depths, in such number as will fairly represent the lot, three to six, from a canal-boat or barge and at depths of a foot or more, two from a car, and more or less from a pile, depending on its size. When the sand is in a pile the coarser grains will have rolled to the bottom, so care must be exercised not to take the sand from that point or the top alone. It is also well to dig some distance into the heap for some scoopsful.

All the sand thus collected is dried, and, if large in amount, is made into a heap, cut back and forth with shovels like a batch of concrete and quartered, all but one quarter being rejected. This is continued until the heap is reduced to such a size that it can be sampled by rolling first in one direction and then at right angles on brown paper and halving the mass, this being done several times until it is reduced to the required size for shipping.

Fourth. Sand from Platform. Samples of the hot screened sand in use in the mixer should be taken from the spout of the sand-bin while the sand is running out freely into the box in the process of filling it. It should be collected by running a shovel or scoop back and forth several times along the edge of the distributor and then sampling the lot so gathered by rolling on paper in the usual way.

Dust and Filler.—The fine material proposed for use as a filler should be examined to determine the best source of supply available, and its character. An amount sufficient to fill an ordinary tin box used for asphalt cement is sufficient to send to the laboratory.

Fluxes.—A tin can of the flux holding a pint should be sent to the laboratory for examination before using it, in order to determine its character and the amount necessary to make an asphalt cement of suitable consistency.

Asphalt Cement.—Samples of asphalt cement should be examined for consistency either at the plant or at the control laboratory at frequent intervals, and also before being put in use, and at any time afterward that any additional amount of flux has been added to it to correct any hardening which has taken place. If the asphalt cement in any melting tank is not exhausted in one days run and is used the next day, or several days afterward, its consistency should be again controlled at the plant or at the control laboratory.

Surface Mixtures.—Samples of surface mixtures should be taken for analysis daily, or oftener, for important work. The method of taking these samples is described as follows in "The Modern Asphalt Pavement":

"**Sampling Surface Mixture.**—A small wooden paddle with a blade 3 to 4 in. wide, 5 or 6 in. long, and 1/2 in. thick, tapered to an edge at one end and with a convenient handle at the other, is used to take as much of the hot mixture from the wagon as it will hold, being careful to avoid any of the last droppings from the mixer which may not be entirely representative of the average mixture. Samples of mixture should never be taken from the mixer itself, but only from the wagon after mixing is completed.

"In the meantime a piece of brown Manila paper with a *fairly smooth* surface, 10 or 12 in. wide, and torn off at the

same length from a roll of this paper, which can be had at any paper warehouse, is creased down the middle and opened out on some very firm and smooth surface of wood, not stone or metal, which would conduct heat too rapidly. The hot mixture is dropped into the paper sideways from the paddle and half of the paper doubled over on it. The mixture is then pressed down flat with a block of wood of convenient size until the surface is flat. It is then struck five or six sharp blows with the block, until the pat is about 1/2 in. thick. The paper should then be opened and the pat trimmed with an ordinary table knife or spatula to a size of about 2 1/2 by 4 in., and a crease made along the narrower edge at a distance of 1/2 in. to facilitate breaking off a piece for analysis when the pat is cold. Before the mixture is entirely cold the proportions of sand, dust, and asphalt cement, together with the sample number, date, and abbreviation of the name of the city where the sample is taken, is impressed upon it with steel stamps in letters and figures 1/2 in. high. The paper is also marked with a rubber stamp, identifying it with the pat.

"Additional information as to street, kind of dust, asphalt, etc., can also be provided for in blank spaces opposite headings printed by the rubber stamp. Such a stamp may be arranged as follows:

Name of city.........................
Sample number.........................
Date and hour.........................
Street.................................
Sand, coarse...........................
Sand, medium..........................
Sand, fine.............................
Filler, kind...........................
A. C...................................
Asphalt, source........................
Flux, kind.............................
Penetration A. C.......................
Temperature...........................

"The pat papers should be wrapped about the pat when cold and both placed in a heavy clasp envelope for mailing at *parcel post rates*.

"The pat paper is sent because the stain made upon it by the asphalt of the hot mixture, when considered in connection with the temperature of the mixture as it goes on

the street, is of great value in determining whether a suitable amount of bitumen is present. Nothing should be written on the pat paper, as this renders the entire pat liable to letter rates in mailing, but the information required may be sent by filling in the blanks furnished by the rubber stamp on a postal card and mailing this at the same time."

Further detail in regard to the collection of samples is given in Chapter XVII of the book which has been cited.

CHAPTER XVIII

REFERENCE TABLES

BEAUMÉ, SPECIFIC GRAVITY AND POUNDS PER GALLON AT 60° F.

Beaumé	Specific gravity	Lbs. in U. S. gal.	Specific gravity	Lbs. in U. S. gal.	Beaumé
10.0	1.000	8.33	1.000	8.33	10.0
11.0	.993	8.27	.995	8.29	10.7
12.0	.986	8.21	.990	8.25	11.4
13.0	.979	8.16	.985	8.21	12.1
14.0	.973	8.10	.980	8.16	12.9
15.0	.966	8.05	.975	8.12	13.6
16.0	.959	7.99	.970	8.08	14.3
17.0	.953	7.94	.965	8.04	15.1
18.0	.947	7.88	.960	8.00	15.9
19.0	.940	7.83	.955	7.96	16.6
20.0	.934	7.78	.950	7.91	17.4
21.0	.928	7.73	.945	7.87	18.2
22.0	.922	7.68	.940	7.83	19.0
23.0	.916	7.63	.935	7.79	19.8
24.0	.910	7.58	.930	7.75	20.6
25.0	.904	7.53	.925	7.71	21.4
26.0	.898	7.48	.920	7.66	22.3
27.0	.893	7.44	.915	7.62	23.1
28.0	.887	7.39	.910	7.58	24.0
29.0	.882	7.34	.905	7.54	24.8
30.0	.876	7.30	.900	7.50	25.7
31.0	.871	7.25	.895	7.46	26.6
32.0	.865	7.21	.890	7.41	27.4
33.0	.860	7.17	.885	7.37	28.3
34.0	.855	7.12	.880	7.33	29.3
35.0	.850	7.08	.875	7.29	30.2
36.0	.845	7.04	.870	7.25	31.1

C. °	F. °	C. °	F. °	C. °	F. °	C. °	F. °	C. °	F. °
−29	−20.2	17	62.6	63	145.4	109	228.2	155	311.0
28	18.4	18	64.4	64	147.2	110	230.0	156	312.8
27	16.6	19	66.2	65	149.0	111	231.8	157	314.6
26	14.8	20	68.0	66	150.8	112	233.6	158	316.4
25	13.0	21	69.8	67	152.6	113	235.4	159	318.2
24	11.2	22	71.6	68	154.4	114	237.2	160	320.0
23	9.4	23	73.4	69	156.2	115	239.0	161	321.8
22	7.6	24	75.2	70	158.0	116	240.8	162	323.6
21	5.8	25	77.0	71	159.8	117	242.6	163	325.4
20	4.0	26	78.8	72	161.6	118	244.4	164	327.2
19	2.2	27	80.6	73	163.4	119	246.2	165	329.0
18	0.4	28	82.4	74	165.2	120	248.0	166	330.8
17	+1.4	29	84.2	75	167.0	121	249.8	167	332.6
16	3.2	30	86.0	76	168.8	122	251.6	168	334.4
15	5.0	31	87.8	77	170.6	123	253.4	169	336.2
14	6.8	32	89.6	78	172.4	124	255.2	170	338.0
13	8.6	33	91.4	79	174.2	125	257.0	171	339.8
12	10.4	34	93.2	80	176.0	126	258.8	172	341.6
11	12.2	35	95.0	81	177.8	127	260.6	173	343.4
10	14.0	36	96.8	82	179.6	128	262.4	174	345.2
9	15.8	37	98.6	83	181.4	129	264.2	+175	+347.0
8	17.6	38	100.4	84	183.2	130	266.0	176	348.8
7	19.4	+39	+102.2	85	185.0	131	267.8	177	350.6
6	21.2	40	104.0	86	186.8	132	269.6	178	352.4
5	23.0	41	105.8	87	188.6	133	271.4	179	354.2
4	24.8	42	107.6	88	190.4	134	273.2	180	356.0
3	26.6	43	109.4	89	192.2	135	275.0	181	357.8
2	28.4	44	111.2	90	194.0	136	276.8	182	359.6
1	30.2	45	113.0	91	195.8	137	278.6	183	361.4
0	32.0	46	114.8	92	197.6	138	280.4	184	363.2
+1	33.8	47	116.6	93	199.4	139	282.2	185	365.0
2	35.6	48	118.4	94	201.2	140	284.0	186	366.8
3	37.4	49	120.2	95	203.0	141	285.8	187	368.6
4	39.2	50	122.0	96	204.8	142	287.6	188	370.4
5	41.0	51	123.8	97	206.6	143	289.4	189	372.2
6	42.8	52	125.6	98	208.4	144	291.2	190	374.0
7	44.6	53	127.4	99	210.2	145	293.0	191	375.8
8	46.4	54	129.2	100	212.0	146	294.8	192	377.6
9	48.2	55	131.0	101	213.8	147	296.6	193	379.4
10	50.0	56	132.8	102	215.6	148	298.4	194	381.2
11	51.8	57	134.6	103	217.4	149	300.2	195	383.0
12	53.6	58	136.4	104	219.2	150	302.0	196	384.8
13	55.4	59	138.2	105	221.0	151	303.8	197	386.6
14	57.2	60	140.0	106	222.4	152	305.6	198	388.4
15	*59.0*	*61*	141.8	+107	+224.6	153	307.4	199	390.2
16	*60.8*	*62*	143.6	108	226.4	154	309.2	200	392.0

TEMPERATURES, CENTIGRADE AND FAHRENHEIT.—(*Continued*)

C. °	F. °	C. °	F. °	C. °	F. °	C. °	F. °	C. °	F. °
201	393.8	223	433.4	245	473.0	267	512.6	289	552.2
202	395.6	224	435.2	246	474.8	268	514.4	290	554.0
203	397.4	225	437.0	247	476.6	269	516.2	300	572.0
204	399.2	226	438.8	248	478.4	270	518.0	310	590.0
205	401.0	227	440.6	249	480.2	271	519.8	320	608.0
206	402.8	228	442.4	250	482.0	272	521.6	330	626.0
207	404.6	229	444.2	251	483.8	273	523.4	340	644.0
208	406.4	230	446.0	252	485.6	274	525.2	350	662.0
209	408.2	231	447.8	253	487.4	275	527.0	360	680.0
210	410.0	232	449.6	254	489.2	276	528.8	370	698.0
211	411.8	233	451.4	255	491.0	277	530.6	380	716.0
212	413.6	234	453.2	256	492.8	278	532.4	390	734.0
213	415.4	235	455.0	257	494.6	279	534.2	400	752.0
214	417.2	236	456.8	258	496.4	280	536.0	410	770.0
215	419.0	237	458.6	259	498.2	281	537.8	420	788.0
216	420.8	238	460.4	260	500.0	282	539.6	430	806.0
217	422.6	239	462.2	261	501.8	283	541.4	440	824.0
218	424.4	240	464.0	262	503.6	284	543.2	450	842.0
219	426.2	241	465.8	263	505.4	285	545.0	460	860.0
220	428.0	242	467.6	264	507.2	286	546.8	470	878.0
221	429.8	+243	+469.4	265	509.0	287	548.6	480	896.0
222	431.6	244	471.2	266	510.8	288	550.4	490	914.0
								500	932.0

DATA, ROCK

Rock	Force gravity	Weight per cu. ft. lb.	Weight per cu. yd. broken stone	
			48 per cent. voids	40 per cent. voids
Trap	2.90	181	2538	2932
Trap and Gabbro. . .	3.00	187	2619	3029
Limestone and Granite	2.65	165	2316	2617

Concrete

1 barrel of Portland cement, or four bags, will lay, ordinarily, 6 sq. yd. of 1 : 3 : 6 concrete.

Binder or Intermediate Course

9 cu. ft. of loose hot binder will lay 6.6 sq. yd. of 1.5-in. intermediate course.

Sheet Asphalt Surface

9 cu. ft. of loose hot surface mixture will lay 5.1 sq. yd. of 2-in. pavement.

INDEX

A

B

G

H

I

L

M

N

P

R

S